BUREAU OF ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

JOHN T. LONSDALE, Director

Report of Investigations—No. 12

Geology of the Blacklands Experimental Watershed, Near Waco, Texas

By

HORACE R. BLANK, NORVAL L. STOLTENBERG, AND
HARRY H. EMMERICH

March 1952

BUREAU OF ECONOMIC GEOLOGY
The University of Texas
Austin 12, Texas

JOHN T. LONSDALE, Director

Report of Investigations—No. 12

Geology of the Blacklands Experimental Watershed, Near Waco, Texas

By

HORACE R. BLANK, NORVAL L. STOLTENBERG, AND
HARRY H. EMMERICH

March 1952

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY OF THE BLACKLANDS EXPERIMENTAL WATERSHED, NEAR WACO, TEXAS[1]

Horace R. Blank,[2] Norval L. Stoltenberg,[3] and Harry H. Emmerich[4]

ABSTRACT

The Blacklands Experimental Watershed, a hydrologic research project of the Soil Conservation Service located about 15 miles southeast of Waco, Texas, is underlain by marls and chalks belonging to the Taylor group of the Gulf series of the Cretaceous system, which, in conformity with the general structure of the Gulf Coastal Plain, dip east-southeastward at an angle a little steeper than the general slope of the land surface.

The lowest strata cropping out in the experimental watershed are part of the Wolfe City member of the Taylor marl and consist of about 110 feet of sandy marl containing numerous small lenses of hard calcareous sandstone. They are transitional upward into about 40 feet of silty marl, in which the sand or silt is too fine to be visible to the unaided eye.

Overlying the silty marl is a stratum of hard chalk, 8 to 25 feet thick, belonging to the Pecan Gap member of the Taylor marl. There is some evidence that the chalk—silty marl contact is an unconformity. This contact is the only easily identified stratigraphic marker in the experimental area. The chalk is hard enough to have some effect on the topography and the soil depth and brittle enough to influence greatly the distribution of the ground water.

The chalk is transitional upward into 90 to 100 feet of highly calcareous marl. Near the southeast corner of the experimental area this marl grades upward into another zone of about 13 feet of soft chalk, which in turn passes transitionally upward into additional highly calcareous marl.

Remnants of an upland gravel, consisting merely of pebbles and cobbles scattered in the soil, occur on a few of the hilltops in the southwest corner of the experimental area and probably belong to the Uvalde (Pliocene?) formation. The valleys of Brushy Creek and its principal tributaries are partly filled with terrace alluvium consisting entirely of transported marl mixed with sand and pebbles and believed to be Pleistocene in age. Near the present stream channels there are also deposits of Recent alluvium consisting chiefly of transported soil.

Partial chemical analyses and mechanical analyses of the acid-insoluble residues bring out some of the differences between the Wolfe City, Pecan Gap, and alluvial formations, as well as differences between the oxidized and unweathered rocks. The intimate relation between the rocks and the distribution of the soil series is discussed.

The boundary between the Pecan Gap lower chalk and the Wolfe City silty marl is traced from Big Creek near Mart through the experimental watershed to Brazos River southwest of Marlin. It is shown that most of the chalk outcrops in this region described by other investigators correspond to the less definite upper chalk rather than to this lower zone. The Pecan Gap belt of outcrop as shown on the geologic map of Texas (Darton et al., 1937) is too narrow and too far east to include both these chalks. At some places it has been based on the lower zone, at others on the upper.

INTRODUCTION

Location and History

The Blacklands Experimental Watershed lies partly in McLennan and partly in Falls County, Texas, about 15 miles southeast of Waco and between the towns of Riesel and Mart (fig. 1 and Pl. II). It is composed of farms totalling about 6,350 acres, 841 acres being owned by the Government. Most of this land forms the upper part of the watershed of Brushy Creek, a tributary of Big Creek, which in turn is tributary to Brazos River. The project also includes the headwaters of a tributary of

[1]Work performed under a cooperative agreement between the Texas Agricultural Experiment Station and the Soil Conservation Service, U. S. Dept. of Agriculture. Published with the permission of the Soil Conservation Service, U.S.D.A.

[2]Formerly associate geologist, Soil Conservation Service.
[3]Formerly junior soil technologist, Soil Conservation Service.
[4]Formerly junior soil technologist, Soil Conservation Service.

Brushy Creek which joins that stream outside the experimental area.

The experimental watershed was established in 1936 for the study of hydrologic problems as affected by agricultural practices within the general sphere of the Soil Conservation Service. This study was a part of the work of the Hydrologic Division of the Office of Research of the Soil Conservation Service in cooperation with the Texas Agricultural Experiment Station. Other cooperators under formal agreement were the U. S. Weather Bureau and the Division of Cotton Insect Damage of the

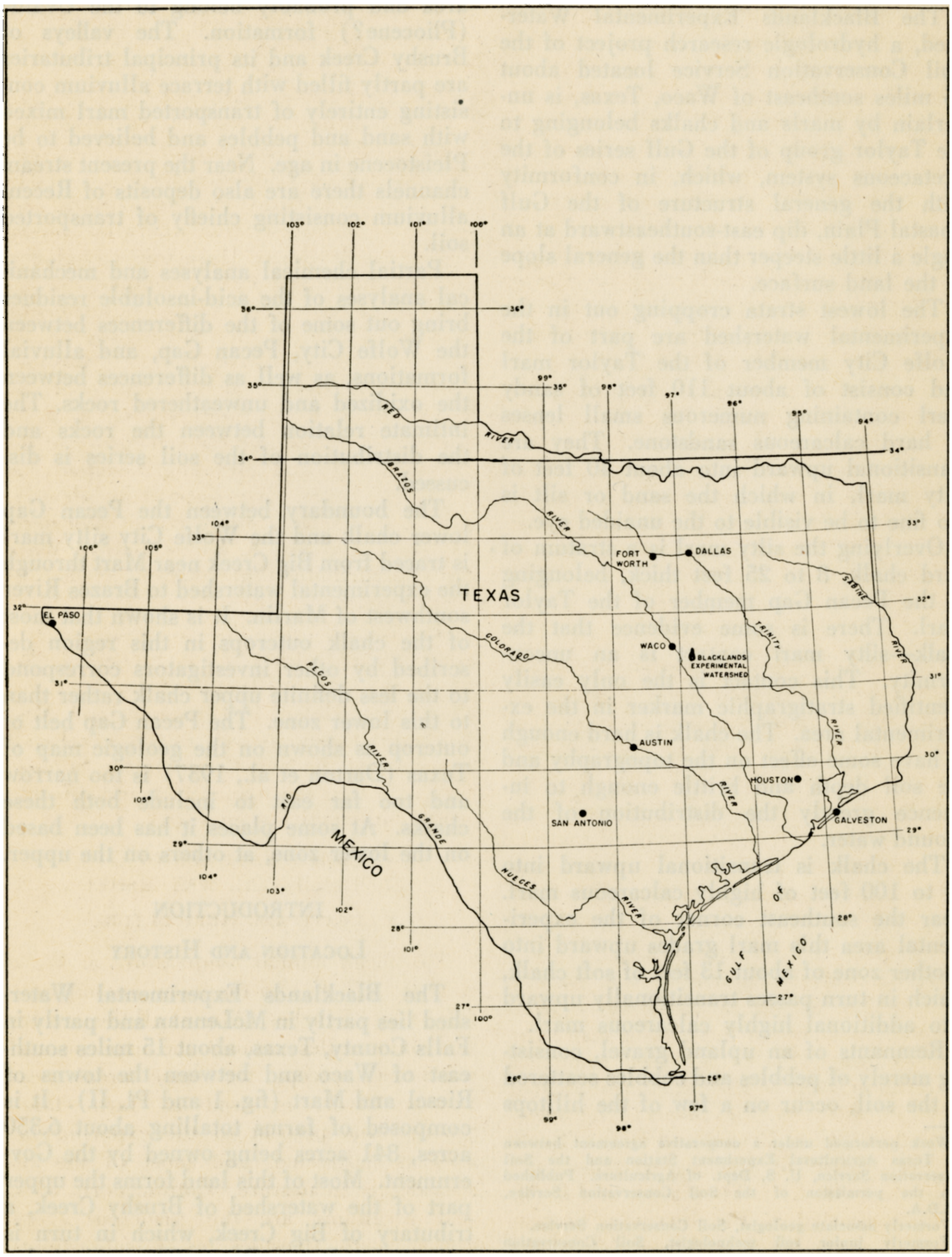


Fig. 1. Index map of Texas showing location of the Blacklands Experimental Watershed.

U. S. Bureau of Entomology and Plant Quarantine.

Preliminary geologic studies of the region were made in connection with the selection of a suitable location for the experimental watershed early in 1936. When the project was established, more detailed studies of all outcrops occurring within the experimental area were made. Numerous auger holes were bored by hand labor throughout the area at various times between 1936 and 1940, many of which were cased with pipe and converted into observation wells for ground-water studies. Favorable rainfall conditions made possible more accurate surveys of the seeps along the lower edge of the Pecan Gap chalk in 1941, and this boundary was traced from the experimental area into the adjoining region at the same time. Ground-water studies were carried on from 1936 to 1942.

A general description of the project and its work may be found in U. S. Department of Agriculture Hydrologic Bulletin 5 (Baird, Lauritzen, et al., 1942). Other publications giving data from the project are Hydrologic Bulletin 2 (Baird, Jenkins, et al., 1942) and ground-water graphs (Potter and Blank, 1939).

Acknowledgments

Geology and ground-water studies at the experimental watershed were in charge of H. R. Blank from January to July 1936 and from October 1937 to their discontinuance in September 1942. N. L. Stoltenberg was continuously associated with the project from its beginning until January 1941 and was in active charge of the geology and ground-water work from July 1936 until October 1937, during which time he was assisted by H. H. Emmerich.

Throughout the course of the work a great deal of assistance was received from all other members of the project staff. The geologic map (Pl. I) is based upon the topographic map of the experimental area made in 1936 by the project engineers. M. G. Santi, C. S. Bryan, and J. T. O'Brien surveyed most of the auger holes and wells. S. Folk, C. J. Thomason, and E. M. Lawhon assisted in the surveying, supervision of auger holes, and assembly of the data. A. J. Stewart and J. E. Poag carried out the mechanical analyses. The selection of the experimental watershed was under the supervision of D. B. Krimgold; after the establishment of the project all work was in charge of R. W. Baird, D. S. Jenkins, G. E. Byars, and L. A. Westby, successively project supervisors, under the general direction of C. E. Ramser, chief, hydrologic division, and M. L. Nichols, chief of research, Soil Conservation Service.

The authors are also indebted for valuable assistance to the U. S. Geological Survey, the Department of Geology and the Bureau of Economic Geology of The University of Texas, the Agricultural Adjustment Administration of Falls County, the Texas Highway Department engineers in McLennan and Falls counties, and the several landowners in the experimental watershed. Dr. L. W. Stephenson of the U. S. Geological Survey, Drs. F. L. Whitney and H. B. Stenzel of The University of Texas, Prof. F. E. Smith of the A. & M. College of Texas, and the laboratory of the Humble Oil and Refining Company at Houston, Texas, have assisted by identifying fossils. Mr. Frank Bryan, formerly of Waco, and Mr. A. Henry Bell of Waco have contributed information about the local geology.

Thanks are also due to Messrs. C. L. Baker, S. S. Goldich, H. B. Stenzel, L. W. Stephenson, John Teagle, John T. Lonsdale, Mrs. Helen J. Plummer, and Miss Josephine Casey, as well as to several staff members of the Soil Conservation Service, for reviewing the manuscript and offering many constructive suggestions.

GENERAL FEATURES OF THE EXPERIMENTAL WATERSHED

Climate and Agriculture

The mean annual temperature at Waco is about 67° F. and the mean annual rainfall about 35 inches. Almost all the country for many miles around the experimental watershed, except for some areas near Brazos River, is used as farm land. Seventy-nine percent of the experimental area is cultivated, and most of the remainder is in pasture. Cotton, corn, oats, and sorghums are the principal crops grown, with livestock as a subordinate source of income.

Geology

The Blacklands Experimental Watershed lies within the Black Prairie of Texas. The underlying rocks are marine sediments belonging to the Taylor group of the Upper Cretaceous, or Gulf series of the Cretaceous system, and consist of sandy marl, silty marl, chalk, highly calcareous marl, another chalk, and another highly calcareous marl, in ascending order. All dip east-southeastward toward the Gulf of Mexico at a gentle angle, which, however, is a little steeper than the general slope of the land surface. The successive formations therefore intersect the surface in parallel bands, which cross the experimental area from southwest to northeast. On a few hilltops these Cretaceous strata are thinly covered, unconformably, by upland gravel deposits of probable Pliocene age, and along the principal drainageways by ancient and recent flood-plain deposits.

A large number of borings on the experimental watershed have shown that all the geologic materials are extensively oxidized to a depth of 20 to 30 feet below the ground surface, which has changed their color and appearance from that of the unaltered rock. This zone of oxidation is somewhat thicker on the hills than in the valleys. For several feet immediately below the soil the rock is ordinarily considerably decayed.

None of the geologic formations is very firmly consolidated, the chalk being the only one that at all approaches hard rock. In the zone of oxidation most of the other materials can be excavated even without the use of a pick. With increasing depth the marls become harder and tougher and thus difficult to excavate.

The entire experimental area is mantled by deep soil, generally black, which originally supported a vegetation consisting chiefly of tall grass, with trees and brush along the principal drainageways. Since the greater part of the watershed has been brought under cultivation, considerable soil erosion has occurred, resulting here and there in the formation of bare spots and gullies, which together with the banks of the larger stream channels are the only places where outcrops of the underlying strata can be seen.

Topography[5]

The topography of the experimental watershed is gently rolling, the elevation ranging from 464 to 592 feet above sea level. Long, smooth slopes are common, and drainageways are rather widely spaced. Divides are commonly flat and poorly defined. Only 3 percent of the area has a slope greater than 6 percent.

The lower of the two chalks, which crosses the experimental area as a narrow belt (Pl. I), is slightly more resistant to erosion than the other stratigraphic units. It forms a poorly developed low cuesta facing toward the northwest. This may be seen at the gap in the eastern ridge of Brushy Creek watershed just north of county road 225 and also near the intersection of State highway No. 164 and road 223, northeast of the project area. The hill on which the Government buildings stand (approximate Lat. 31°28′40″, Long. 96°53′10″), as well as the corresponding hill northeast of it (approximate Lat. 31°29′10″, Long. 96°52′30″), is capped by outliers of the chalk. For about 2 miles south-southwest from the Government buildings, the cuesta is emphasized by the rapid downcutting of the headwaters of Sandy and Big Sandy creeks (Pls. I and II).

The greater resistance of the chalk also produces steeper slopes, a more irregular topography, and a greater number of small watersheds in a given acreage than are commonly found in the remainder of the experimental area. The formation of numerous small drainages is probably aided by the ground-water seeps which occur along the outcrop of the base of the chalk.

Drainage

Brushy Creek flows in a general southeasterly direction across the Cretaceous strata, which suggests that it is one of the older consequent streams of the Coastal Plain.[6] Its tributaries, however, tend to

[5]A topographic map on a scale of 1 inch equals 400 feet and a contour interval of 2 feet appears in Hydrologic Bulletin 5 (Baird, Laúritzen, et al., 1942).

[6]It is recognized that a Tertiary or early Quaternary gravel plain, of which the upland gravels called Uvalde in this report are remnants, must have buried most of the original coastal-plain topography. There is not enough evidence to show whether Brushy Creek originated on this gravel plain or whether it re-excavated an earlier valley in the Cretaceous sediments.

follow a northeasterly or southwesterly direction, following the strike of the rocks. This is especially true in the lower (southern) part of the experimental watershed, where dissection is further advanced. A trellis drainage pattern is therefore in process of development (Pls. I and II), which is rhomboidal rather than strictly rectangular.

In the course of this dissection of the elevated coastal plain, certain streams having a more direct route to Brazos River, or working on softer rocks, are able to cut down more rapidly and to capture parts of other stream systems having a gentler gradient. This appears to have occurred near the headwaters of Brushy Creek, which is a beheaded stream. A point on the boundary divide of the experimental watershed on road 221A (Pl. I) is more than 25 feet lower than the present headwaters of Brushy Creek near road 219, about 3,000 feet away. It seems evident that this low point was formerly in the valley of Brushy Creek, and that the headwaters of a tributary of Trading House Creek, which flows into Tehuacana Creek and thence into Brazos River near Waco, have worked back from the north and have captured and reversed the flow of the former headwaters of Brushy Creek. The present source of the latter stream is in the valley of one of its former tributaries. Judging from the general topography of its present watershed, it seems unlikely that the drainage area which has been lost by Brushy Creek amounts to more than 3 or 4 square miles. The process is still going on, however, and the present headwaters of Brushy Creek are due to be captured in the geologically very near future. Comparatively slight artificial changes in the drainage of certain fields in the vicinity could accomplish this diversion at the present time.

Because of the impermeable nature of most of the underlying rocks in the experimental watershed and its vicinity, the ground water is small in amount and is irregularly distributed. Consequently many of the drainageways flow only after rains; others receive contributions of ground water for a few months after a prolonged period of rainfall, but all of this may be lost by evaporation before it flows very far. Brushy Creek itself is normally dry during the late summer and fall. The large amount of easily eroded material carried from the higher slopes by the occasionally very intense rains builds flood plains along the lower courses of all but the smallest streams. Deep channels, in places bordered by natural levees, are maintained by average rains and ground-water flow and meander through the flood plains on a very low gradient.

ROCKS OF THE EXPERIMENTAL WATERSHED

Areal Distribution of the Geologic Units

The areal distribution of the geologic units within the experimental watershed is shown in Plate I, which also shows the location of auger holes and wells.

The boundary shown between the Pecan Gap lower chalk and the Wolfe City silty marl has been rather accurately determined over most of the experimental area through numerous exploratory borings, location of ground-water seeps, material excavated by crawfish, and similar indications. The other boundaries of the Cretaceous units are based on the evidence of outcrops and borings but are quite arbitrary and generalized. The upper chalk at the southeast corner of the experimental area has been located chiefly by interpretation from holes 1000 and 1010 and from the outcrops on Brushy Creek and its tributary.

The upland gravel (Uvalde formation), the terrace alluvium, and the Recent alluvium are shown as patterns superimposed on the older formations. In outlining them the distribution of soil types, shown on the conservation survey map in Hydrologic Bulletin 5 (Baird, Lauritzen, et al., 1942) has been of very great assistance. Because of the difficulty of identifying the alluvial marl and its irregular distribution, the boundaries shown for the terrace alluvium are probably the least accurate of the geological boundaries shown in Plate I, and are largely the result of interpretation, especially on the spurs between the tributaries of Brushy Creek. The terrace alluvium is not shown where it is overlain by the Recent alluvium.

Table 1
GEOLOGIC UNITS AT THE BLACKLANDS EXPERIMENTAL WATERSHED, TEXAS

System	Series	Group or formation	Member	Thickness (feet)	Unit designation in this report	Description	Occurrence
Quaternary	Recent			0–15	Recent alluvium	Chiefly transported soil—sandy in northwestern part and along Brushy Creek; clayey in southeastern part	Borders stream channels; also includes sheet wash
	UNCONFORMITY						
	Pleistocene?			0–15	Terrace alluvium	Alluvial marl—sandy in northwestern part; highly calcareous in southeastern part	Partly fills nearly all valleys and extends up sides
	Pleistocene			?	Brazos River terraces	Gravel, sand, and silt—reddish	May occur in traces in northwestern part of experimental area—prominent a short distance farther west
UNCONFORMITY							
Tertiary	Pliocene?	Uvalde gravel?		0–1	Upland gravel (Uvalde formation)	Pebbles and cobbles	Loose in soil on tops of certain hills
UNCONFORMITY							
Cretaceous	Upper Cretaceous or Gulf	Taylor marl	Pecan Gap	?	Upper highly calcareous marl	Highly calcareous marl	Southeast of experimental area
				TRANSITION			
				13±	Upper chalk	Soft chalk alternating with chalky marl	Borders experimental area on southeast
				TRANSITION			
				90–100	Lower highly calcareous marl	Highly calcareous marl	Southeastern half of experimental area
				TRANSITION			
				8–25	Lower chalk	Hard chalk—glauconitic in lowermost 1 or 2 feet	Diagonally across middle of experimental area
			UNCONFORMITY				
			Wolfe City	40	Silty marl	Clay-marl containing large amounts of silt invisible to naked eye	Northwest of and parallel to the lower chalk
				TRANSITION			
				100+ (continues beyond area studied)	Sandy marl	Clay-marl containing sand visible to naked eye and commonly small lenses of hard calcareous sandstone also	Northwestern third of experimental area

Wolfe City Member of Taylor Marl

Divisions.—The lowest strata cropping out in the experimental watershed are sandy and silty marls. Their band of outcrop contains approximately the northwestern half of the project area and much additional territory farther northwest; its exact limit in this direction was not investigated. They underlie the entire project area at depths increasing toward the southeast.

These marls may be arbitrarily divided into two parts, the sandy marl and the silty marl. The sandy marl contains visible sand and usually also numerous lenses of hard calcareous sandstone. In the overlying silty marl the abundant silt particles are too small to be visible to the unaided eye. In this region these divisions grade into each other vertically but apparently not laterally, and hence they are convenient stratigraphic distinctions.

Sandy marl.—The sandy marl may be seen in the road ditch on county road 221A northeast of well 850 (Pl. I), on road 229 just east of its easterly intersection with road 228, and on road 233 west of well 352 and also near well 1012. It also crops out in a large gully at about Lat. 31°30′35″, Long. 96°53′35″. Better outcrops may be seen northwest of the project area on the headwaters of Maness Creek near the road crossing at approximate Lat. 31°31′00″, Long. 96°55′30″ (loc. 27, Pl. II). On Brushy Creek there is a small exposure at the bend at approximate Lat. 31°29′25″, Long. 96°52′50″. Transitional marl in which the sand is barely visible occurs where the creek has cut through a neck at approximate Lat. 31°29′20″, Long. 96°52′30″.

Borings have shown that the unoxidized marl of these strata is bluish gray in the coarser parts to bluish black in the finer layers, but near the surface it is usually a rusty yellowish-brown color, in places mottled with gray in the less completely oxidized portions. Large exposures usually show imperfect stratification, due at least in part to poorly developed bedding fractures.

Sand or silt is abundant throughout the marl, and its coarseness increases downward, although probably not with absolute regularity, from the top of the silty marl. As the sand becomes coarser it tends to segregate in distinct laminae and in gray lenses and pockets enclosed in darker material which is richer in silt and clay. As these lenses increase in size and in coarseness of texture, many of them are found cemented into hard sandstone by fine-grained crystalline calcite. There seems to be no definite arrangement of these sandstone lenses, except that their long axes are parallel to the bedding of the marl. They range from about half an inch to about 2 feet across, and they are not continuous at any one horizon except for very short distances. The cementation appears unrelated to any weathering process, for the sandstone lenses are found in both the oxidized and unoxidized marl and have been recovered in borings from depths as great as 200 feet.

In thin section the marls of these strata are composed of a ground-mass of very fine silt, carbonate, and clay, ranging in texture from grains about 0.017 mm in diameter down to cloudy material beyond the resolving power of the microscope. Thickly scattered through the ground-mass are grains of coarser silt and sand, almost all sharply angular. In the sandy marl beds there is a noticeable hiatus between the size ranges of the admixed silt and sand and of the ground-mass. A few microscopic fossils are present.

Most of the sand and coarser silt grains are composed of quartz, accompanied by considerable chert and some feldspar, part of which is plagioclase. Micas are rare, although decayed biotite and chlorite are occasionally seen. Heavy minerals include a considerable amount of marcasite in spherical aggregates, especially in the unoxidized material, and lesser amounts of ilmenite, zircon, and colorless garnet. A little tourmaline and rutile are also present. The zircon is of two distinct types, well-preserved zirconoids and much-rounded grains.

All the sandy marl found on the experimental watershed, except a few of the uncemented very sandy lenses, contains enough carbonate to effervesce with dilute hydrochloric acid. Judging from the analyses shown in table 3, its calcium carbonate content ranges from 5 to 15 percent.

Megascopic fossils are rather scarce in the sandy and silty marls, but occasional shell fragments occur of which *Inoceramus* is the only recognizable genus.

Silty marl.—Typical silty marl crops out on the lower reaches of the stream flowing from watershed Y and at several sharp bends of Brushy Creek just above its junction with this stream. It is also exposed in gullies at a property corner at approximate Lat. 31°29′17″, Long. 96°52′ 45″, and on road 238 just south of well 249.

The differences between the silty and sandy marls are of degree rather than of kind. In appearance the silty marl is similar to the sandy marl in the corresponding state of oxidation, except that it is more uniform because of the absence of sandy lenses and laminae. At some places the unoxidized silty marl has a greenish cast. Stratification is less noticeable than in the sandy marl but is more noticeable than in the highly calcareous marls of the Pecan Gap member.

Although the silt abundant throughout this marl is invisible to the unaided eye, it can readily be felt between the teeth, and it is easily seen under the microscope in thin section. The difference in size between the admixed silt and the ground-mass is much less marked than in the sandy marl.

The silty marl is richer in carbonate and in clay than the sandy marl and consequently poorer in silica (tables 3 and 4). As in the sandy marl, megascopic fossils are not common, although microscopic fossils are generally present.

The silty marl overlies the sandy marl and is in turn overlain by a stratum of chalk which, as described below, is regarded as belonging to the Pecan Gap member of the Taylor marl. The silty and sandy marls must therefore be correlated with the Wolfe City member of the Taylor. Although the exact southern limit of this member probably cannot be defined, on the geologic map of Texas (Darton et al., 1937) the strata immediately below the Pecan Gap chalk have been mapped as Wolfe City as far south as Bell County. Dane and Stephenson (1928, p. 50) state ". . . . . . . the 350-foot section included in the Wolfe City sand in southern Hill and southwestern Navarro counties becomes decreasingly sandy southward through Limestone and eastern McLennan counties. Characteristically it is a bedded sandy marl with regular even beds of either pure or slightly sandy marl ranging from ½ to 1 inch thick, with intervening thinner sheets and vermicular pockets of soft clean sand. A few lenses of hard calcareous sandstone may be as much as 4 inches thick." This fairly well describes the sandy marl beds of the experimental watershed. They say also (p. 54), "Toward the southwest (from Prairie Hill) the sandy constituent diminishes and in the vicinity of Mart and Marlin the beds immediately below the chalk are pure marl without perceptible sand content." These are evidently the silty marl beds found on the experimental area.

As calculated from the strike and dip of the chalk—silty marl contact, discussed below, the total thickness of the strata below the chalk in the experimental watershed is about 150 feet. On the basis of the samples obtained from several borings, the uppermost 40 feet of this has been assigned to the silty marl. This thickness was used to calculate the width of the band of outcrop shown in Plate I, and only slight adjustments were needed to make this agree with all the known outcrops.

Pecan Gap Member of Taylor Marl

Lower chalk.—A narrow band of chalk extends irregularly across the middle of the experimental watershed from southwest to northeast, with outliers capping certain isolated hills (Pl. I). The overlying shallow soil has been severely eroded where it has been cultivated on steep slopes, and the white subsoil and decayed chalk appear in the fields. Still more accelerated erosion at a few places has exposed hard ledges, as in the farmyard at locality 5, Plate II (near well 91, Pl. I). Apart from such places outcrops are not common, as the chalk is ordinarily hard enough to resist gullying. Outcrops may be seen, however, in a gully at approximate Lat. 31°27′35″, Long. 96°53′35″, in the right bank of the stream draining watershed Y near spring 28, on Brushy Creek from about 1,000 feet below gaging station G to spring well 26, and in a gully at spring 14, approximate Lat. 31°29′30″, Long. 96°52′00″.

Below the zone of oxidation chalk from borings is bluish gray, somewhat lighter in color than the silty marl beneath it. In the oxidized zone where covered by soil it is usually a pale yellowish-brown or cream color. Where exposed directly to the elements it becomes white. At most places the chalk shows no stratification or lamination, but in outcrops of the basal portion a suggestion of heavy-bedded structure develops on weathering.

The chalk is not so hard as, and is more easily weathered than, the typical chalk of the Austin formation of central Texas. Nevertheless, in both oxidized and unoxidized state it is ordinarily too hard to be grooved by the fingernail, which distinguishes it from the overlying highly calcareous marl. Exposure seems to increase its hardness to some extent. Although where covered by a thin layer of soil it disintegrates rather readily, cutbanks and exposed blocks retain their shape for several years. The chalk is more brittle than any of the other rocks in the project area, and in the zone of weathering it is extensively fractured, a condition of great importance to the distribution of the ground water. It does not, however, possess the finely spaced conchoidal fracture characteristic of the highly calcareous marl.

Most of the lower chalk is too fine to be resolved by the naked eye or by a hand lens and does not contain sand or silt noticeable between the teeth. The apparent grittiness at first felt on chewing a specimen is due to the calcareous fossils and disappears as they gradually are crushed or dissolve. Near the base of the chalk, however, there is in many places a zone of coarser texture, extremely rich in foraminifera, some of which are large enough to be visible. This part of the chalk also contains a little coarse silt or sand, although not so much as in the silty marl below. In its lowermost 1 or 2 feet the chalk also contains numerous rounded grains of glauconite, which are dark green in the unoxidized material but appear merely as rusty spots in the weathered rock.

Thin sections taken from the lower part of the chalk above the glauconitic zone show it to contain much the same materials as the underlying silty marl but in relatively very different amounts. The groundmass is made up of particles ranging from about 0.006 mm in diameter down to beyond the resolving power of the microscope, in a mass of still finer, cloudy material. The particles are nearly all carbonate, as much of the cloudy material also appears to be. Thickly scattered throughout the ground-mass are calcareous fossils, mostly foraminifera, and fossil fragments, of an average size of from 0.04 to 0.09 mm. An appreciable number of angular silt grains of about the same size range are also present but less abundantly than in the underlying silty marl. The unoxidized chalk contains also numerous marcasite balls and irregular black spots which appear to be organic matter.

All the numerous chalk specimens tested effervesce vigorously with cold dilute hydrochloric acid. The chemical analyses in table 3 show a carbonate content for the chalk of between 70 and 80 percent, and rough analyses indicate that it may reach 90 percent in some specimens. On solution in hydrochloric acid the unoxidized chalk leaves a scummy residue of organic material along with the insoluble clay and silt.

Megascopic fossils occur occasionally throughout the chalk and are most numerous near its base. Shells of *Exogyra ponderosa* are found frequently, and of *Durania austinensis* rarely, in the soil throughout the belt of outcrop. The following fossils, from just above the base of the chalk at the site of the Government buildings, have been identified by Dr. F. L. Whitney of The University of Texas:

Inoceramus crippsi var. barabini Meek (?)
Baculites sp., probably asper
Eutrephoceras sp.
Undetermined ammonites

The *Inoceramus* and *Baculites* were found also just above the base of the chalk at hole 1020 on Brazos River (Pl. II) and at other localities.

Numerous borings throughout the experimental area and a few in the adjacent region, as well as outcrops on Big Sandy Creek described below, have shown that the base of the chalk is a sharp contact with the underlying silty marl. Its upper limit is much less definite, and it passes by imperceptible gradations into the overlying highly calcareous marl through a zone of material which is intermediate between the two. Where the full thickness of the chalk is not represented, as where it is overlain by soil or by alluvial marl, the hard rock may be much more sharply defined. Near the belt of outcrop the full thickness of the hard chalk is between 8 and 14 feet. Down the dip it appears to thicken somewhat, and in hole 1010 the thickness was recorded as 22.5 feet.

From its stratigraphic position and its similarity to the chalks described by Dane and Stephenson (1928), Ellisor and Teagle (1934), and Rouse (1944), there seems little doubt that this chalk belongs to the Pecan Gap member of the Taylor marl. Its relation to the chalk outcrops described by these authors is discussed in a following section.

Lower highly calcareous marl.—The southeastern half of the experimental area is immediately underlain by a highly calcareous marl, into which the chalk grades imperceptibly, as above described. This material is exposed in many outcrops along Brushy Creek from the vicinity of spring well 26 (approximate Lat. 31°28′52″, Long. 96°51′50″) to below gaging station J. It also appears in a gully at approximate Lat. 31°28′28″, Long. 96°51′55″, and in gullies along road 337 both east and west of Brushy Creek.

In appearance and properties the highly calcareous marl is the most uniform of all the rocks on the project area. It shows no stratification or lamination, either in outcrops or in small pieces. Where recovered by borings from below the zone of oxidation, this marl has the bluish-gray appearance of the underlying chalk, from which it cannot readily be distinguished except by its lesser hardness. Beneath the soil in the zone of oxidation the marl usually acquires a yellowish-white to tan color, somewhat yellower than the chalk, but where exposed directly at the surface it becomes white like the chalk. The most outstanding difference results from prolonged exposure to the elements. The chalk remains hard for at least several years, but the marl, after a few alternate wettings and dryings, shrinks and checks through the formation of a multitude of conchoidal fractures, probably because of a change in volume with change in moisture content. This permits an outcrop of marl to slump rather easily and crumble away. Thus the highly calcareous marl becomes severely gullied by the concentration of run-off water much more easily than the chalk. This is also true, although to a somewhat lesser degree, of the silty and sandy marls below the chalk.

Thin sections show that, like the chalk, the highly calcareous marl consists of a ground-mass rich in carbonate, through which are scattered numerous tiny calcareous fossils, which nevertheless are less abundant than in the chalk. Silt grains are rare and consist of the same minerals as in the other strata studied. No silt can be detected on chewing the average specimen. As in the chalk, the ground-mass consists of a multitude of grains less than 0.01 mm in diameter and embedded in a cloudy, unresolvable material. Many of the grains are crystalline calcite or dolomite, some being perfect rhombs, but many others are not carbonate and apparently are very fine detrital material. Like the chalk, in thin section the unoxidized marl shows marcasite aggregates and organic matter.

The partial chemical analyses in table 3 show that the highly calcareous marl contains approximately 50 percent calcium carbonate. Table 4 shows that its acid-insoluble portion contains more clay than does the residue from any of the other geologic materials under consideration.

The highly calcareous marl contains fewer megascopic fossils than the chalk but more than either the sandy or the silty marl. Occasional unidentifiable shell fragments and impressions occur, and impressions of *Inoceramus* were noted.

The highly calcareous marl is transitional into hard chalk below and into soft chalk or chalky marl above. Consequently its upper and lower boundaries must be arbitrarily established. In hole 1010, where both upper and lower chalks were penetrated, the thickness of the marl between them was regarded as 94 feet.

In the surrounding region chalk outcrops corresponding to both the upper and the lower chalks of the experimental area have been correlated with the Pecan Gap member of the Taylor group. This term must therefore include the highly calcareous marl between them, and probably also much of the similar marl above the upper chalk.

Upper chalk.—In holes 1000 and 1010, about half a mile southeast of the lower end of the main experimental watershed (Pl. I), thin layers of a bluish-gray soft chalk or chalky marl were found, grading into marl above and below. Similar soft chalk or hard marl, white because more oxidized, was found on the right bank of Brushy Creek at approximate Lat. 31°27′ 47″, Long. 96°50′50″, and on the tributary stream about 900 feet west of this point, just above well 156.

In appearance this chalk cannot be distinguished from the highly calcareous marl just described, except for its slightly greater hardness and accompanying increased brittleness. It is somewhat more resistant to weathering, but the difference is not great enough to give topographic expression to its belt of outcrop.

A thin section of the chalk from hole 1000 shows it to be very similar in texture and structure to the lower chalk and to the highly calcareous marl. In abundance of microscopic fossils it lies between the two. It differs from the lower chalk in its smaller content of the larger silt grains, which are even less abundant than in the highly calcareous marl.

The chemical analyses in table 3 show that this upper chalk is very similar to the lower in carbonate and silica content.

No megascopic fossils have been found directly in the upper chalk at the borings and outcrops just described, but outcrops of highly calcareous marl in the immediate vicinity, and not far distant stratigraphically, have yielded undetermined species of *Inoceramus, Pecten,* and *Ostrea,* and also *Pycnodonte vesicularis. Durania austinensis* has been found loose in the soil. *Diploschiza cretacea minor* has been found in marl outcrops on Brushy and Little Brushy creeks just southeast of, and stratigraphically a little above, this chalk.

In hole 1010 the upper chalk occupied a zone about 13 feet thick; in hole 1000 it was not completely penetrated. Observations at these holes and at the outcrops indicate that within this zone the chalkier layers alternate with softer, marlier layers, but the changes are gradational and not sharp. For this reason any estimate of the thickness must be rather arbitrary.

Upper highly calcareous marl.—The upper chalk is transitional upward into another highly calcareous marl, similar in all its properties to the lower highly calcareous marl already described and indistinguishable from the latter by any lithologic criteria.

The upper highly calcareous marl crops out along Brushy and Little Brushy creeks just south of road 339. Its thickness and extent were not investigated, but judging from the few outcrops visited, its band of outcrop has a width of about 2 miles, beyond which, toward the southeast, the marl gradually becomes appreciably sandy.

It is not known how much of this upper highly calcareous marl should be included in the Pecan Gap member of the Taylor group. In part it may correspond to what has been regarded by some geologists as a southern extension of the Marlbrook marl of Arkansas.

Alluvial and Colluvial Deposits

Classification.—Over much of the experimental area and throughout the surrounding region, especially toward the west and southwest, more or less alluvial material is present. Its former almost continuous extent is attested by the fact that a little sand and a few pebbles are everywhere found in the soil known as the Houston black clay (Baird, Lauritzen, et al., 1942, p. 35), even where this soil rests upon and has apparently been formed exclusively from sand-free highly calcareous marl. The present alluvial deposits vary greatly in composition, thickness, and distribution, but in general they consist of three principal types:

(a) Definite deposits of sufficient thickness to mask the underlying strata nearly completely and to govern the development of the topography and the soils.

(b) Erosion remnants consisting only of the coarser constituents of former alluvial deposits which have been almost completely removed.

(c) Recent colluvial and alluvial material, which consists chiefly of soil and much of which is still being actively shifted. Because of the difficulty of deciding where colluvium ends and alluvium begins, all such material is regarded as alluvium for the present purpose.

As geologic units the alluvial deposits may be classified as follows, beginning with the oldest:

Upland gravel (Uvalde formation)
Terraces of Brazos River
Terrace alluvium along Brushy Creek
Recent alluvium

Upland gravel (Uvalde formation).—Coarse gravel and cobbles are abundant in the soil on the tops of certain of the higher hills and ridges on the western and southwestern borders of the project area, as shown in Plate I, and may be seen near wells 114 and 670. They are even more abundant in a field about 1 mile west-southwest from Trinity Church (loc. 28, Pl. II). Such soils have been mapped as Houston black clay, gravelly phase (Baird, Lauritzen, et al., 1942, p. 35.)

These deposits never amount to definite gravel beds, and in some places they consist merely of occasional cobbles. The cobbles and pebbles are often found far down the adjacent hillsides (as for example east of well 670) and along the stream channels, but their concentration is greatest on the tops of the divides.

Nearly all the pebbles and cobbles in these deposits are well rounded, and a few show evidence of wind faceting. They range up to about 4 inches in diameter, but sizes below "pea gravel" are much less abundant. They consist largely of gray chert and flint, nearly all of which is much devitrified on the outside and in some cases throughout. Quartzites and quartzitic sandstones are also abundant, many of them reddish or purplish. Minor constituents include vein quartz, both milky and colorless, red jasper, silicified wood, decayed gneiss, decayed hornblende schist, and similar metamorphic and igneous rocks which must have come from far distant sources. Limestones are entirely absent, although some of the pebbles show calcium carbonate coatings, which seem now to be in process of solution rather than of deposition.

The devitrification and decay shown by most of the pebbles and cobbles are noteworthy. Only those composed entirely of crystalline quartz are fresh in appearance.

It seems probable that these gravels represent erosion remnants of the earliest fluviatile deposits of the region. No fossils have been found in them, except loose shells of *Exogyra ponderosa* obviously derived from the underlying chalk or marl.

Similar upland interstream gravels are more prominent farther south in central Texas. Although because of the general absence of fossils no exact correlation of the different occurrences has been possible, all of them have been grouped by most writers with the Uvalde formation (formerly called Reynosa by some geologists). A general description of the deposits and a history of the two names is given by Plummer (1933, pp. 777–779). Hill (1901, pp. 346–349) describes gravel "of the Uvalde type" in Bell County, and Deussen (1924, p. 106 and pl. 8) maps occurrences as far north as southern McLennan County. Sayre (1936, pp. 65–67) describes the Uvalde gravel in Uvalde County as containing limestone pebbles and some silt, both of which are absent in the gravels of the experimental watershed. However, Deussen points out that the composition of the deposits varies in the different major drainage basins, and Stenzel (1938, pp. 161–169) notes the total absence of limestone pebbles in the upland (Uvalde) gravels of Leon County.

All the upland interstream gravels, including those on the experimental watershed, are topographically higher, more eroded, and more weathered than any of the terraces which can be related to the present major streams. Early Pleistocene fossils have been found in some of these terraces, and therefore the upland gravels are probably not younger than late Pliocene or oldest Pleistocene (Plummer, 1933, p. 779). As the upland gravels represent the channels or flood plains of the streams at the time of their deposition, all the present topography of this region must have developed since Pliocene time.

Terraces of the Brazos River.—About 1 mile west of the southwestern corner of the project area, and on a generally lower level, much of the land surface is blanketed by a fresh-water deposit containing much reddish gravel and considerable sand. Similar material covers the ridge on which the village of Riesel stands and occurs also on the next ridge to the north and at the intersection of State highways No. 6 and 164 (Pl. II). It is also found extensively in northern Falls County in the region east of Perry.

In these deposits, in contrast to the upland gravels assigned to the Uvalde formation, the finer sizes of pebbles are much more abundant, although cobbles up to 4 inches in diameter are occasionally found. The devitrified flints and cherts of the upland gravel are almost entirely absent, but brown and black flints, only slightly decayed, are very common, as is also milky quartz. Reddish quartzites are also abundant and give a slightly reddish cast to most of the material.

These deposits are sufficiently thick and extensive to change materially the character of the soils and natural vegetation. Where not cultivated they support a growth of post-oak trees. They are found capping the lower hills on both sides of Brazos River in this region and may represent the oldest of the Pleistocene terraces of the river, which are discussed by Deussen (1924, pp. 114–115 and pl. 33) and Hill (1901, pp. 352–360).

A thin sprinkling of similar small reddish pebbles is found on the surface of the soil at many places along the western ridge of the main experimental watershed between roads 225 and 221A (Pl. I). This deposit lies at a higher elevation than the deposits mentioned above and may be the last remnant of a still older terrace. There is a strong suggestion that it may have contributed to the development of the Crockett soils in this vicinity.

In Falls County northwest of Marlin, below the level of the reddish gravel terrace, there is a distinctly different terrace consisting principally of red silt with some clay and characterized by concretions and segregations of white calcium carbonate, several inches in diameter, at shallow depths. This deposit is sufficiently thick and continuous to blanket completely most of the underlying rocks except where it is deeply dissected by gullies or streams. It does not occur on the experimental watershed, but it overlies the type exposure of the Marlin chalk just south of Marlin and adds greatly to the difficulty of tracing the various Cretaceous strata in that vicinity.

Terrace alluvium along Brushy Creek and adjacent streams.—At many places in the experimental area and in the surrounding territory there are extensive alluvial deposits of a nature quite different from the dominantly gravelly or sandy deposits above described. Most of them consist of weathered marl very similar to that formed by decay of the residual marl in their immediate vicinity but containing various amounts of coarse sand and gravel. They occur not only beneath the present flood plains of the principal streams, such as Brushy, Little Brushy, Big, and Trading House creeks, but well up the valley sides and in the valleys of most of the minor tributaries nearly, but not quite, as far as the interstream divides, where they may merge with the colluvial wash from the upland gravel and other deposits capping the hills. In contrast to the upland gravel, however, their position is everywhere clearly related to the main features of the present topography and drainage systems.

Good exposures of these alluvial marls may be seen at many outcrops on Brushy Creek, southward from spring well 26 (Pl. I), at some of which their relation to the residual marl is well shown; also in the gullies on the south side of road 337 about one-quarter mile west of Brushy Creek. A type made up almost exclusively of calcareous materials is exposed in the gully at approximate Lat. 31°28′35″, Long. 96°51′50″, and in the gullies entering Brushy Creek from the east between gaging station G and road 233. The banks of the northernmost of these gullies show the change in the character of the alluvial materials as contributions were received from the headwaters of its stream or from the main creek. A very sandy type of alluvial marl, found also on Brushy Creek watershed, may be seen along the "County Line Road" about 6 miles north-northwest of Mart, just north of the crossing of Trading House Creek.

On the east side of Brushy Creek the entire gently sloping plain, which is about half a mile wide at road 233, is built of alluvial marl.

In contrast to the upland gravel and the Brazos River terrace deposits, the alluvial marls of the present discussion are everywhere characterized by the local, often very local, origin of their constituent materials. In consequence two distinct types of this alluvium occur on the experimental watershed. A sandy alluvial marl, derived chiefly from the sandy marls of the Wolfe City member, is found in the northwestern part of the area, and a highly calcareous alluvial marl, derived from the Pecan Gap member, occurs in tributary valleys of the southeastern part. For a short distance south of the Pecan Gap—Wolfe City contact, the alluvial marl along Brushy Creek is somewhat intermediate between these types, but it soon becomes dominantly calcareous as more and more tributaries enter from Pecan Gap territory. Large pebbles are common in the highly calcareous type and small ones in the sandy type, which suggests that no upland gravel remnants other than those now known have been present in the watershed since before the period of deposition of the alluvial marl.

Because of this local origin, at most places the alluvial marl is very similar in color and appearance to the underlying residual marl, and unless the former contains considerable gravel and sand it is not easily distinguished. The mere presence of a little gravel or sand is not an infallible criterion, because in drier seasons wide cracks form in the soil and often extend far down into the underlying parent material, permitting sand or small pebbles to be blown or washed into any of the residual formations. In outcrops and excavations, however, these filled cracks can usually be detected. Also, where true alluvial marl is present a fine line of demarcation is often visible between it and the underlying residual material. Pebbles, especially the larger ones, are frequently more numerous just above this line. Furthermore, however closely the alluvial marl may resemble the underlying material in texture and composition, its structure indicates that it is made up of a great many small lumps that have previously been separated, as shown by numerous shiny surfaces, which contrast with the duller appearance of the characteristic fracture surfaces of the residual marl. Perhaps because of this structure, gullies start and enlarge much more readily in the alluvial marl. However, all these distinctions require a large and clean exposure, and in borings, unless undisturbed material or large pebbles are recovered, the distinction is quite difficult and is often uncertain.

In thin section the distinction is somewhat easier, since most specimens of alluvial marl contain material coarser than any sand found in the residual marls, even those of the Wolfe City member. Most of these coarser grains in the alluvial marl are well rounded, whereas most of the sand grains in the Wolfe City are sharply angular. The mechanical analyses (table 4) illustrate the much wider range of sand sizes in the alluvial marl. The groundmass of very fine silt, carbonate, and clay, however, appears much the same in both residual and alluvial marls. As seen in table 3, the admixture of material from non-Cretaceous sources may not cause a difference in chemical composition any greater than the variations within the Cretaceous formations themselves.

No fossils have been found in the alluvial marl which appear to be contemporaneous with its deposition. It contains numerous shells eroded from the Cretaceous formations.

From observations at the numerous borings and exposures where the alluvial marl was encountered, it seems unlikely that it is more than 15 feet thick at any place on the experimental watershed. It averages somewhat more than 10 feet thick on the old flood plain of Brushy Creek and between 5 and 10 feet thick in the tributary valleys. These figures include the soil developed from the alluvial marl. Farther up the valley sides it is generally thinner and in many places absent.

Because of scarcity of exposures, irregular distribution, and uncertain identification in borings, the exact extent of the alluvial marl was very difficult to map. Enough evidence was obtained, however, to show that the greater part of it forms a terrace or terraces along Brushy Creek and its tributaries. It is therefore referred to in this report as the terrace alluvium. The topography suggests that there may be at least two terraces, the one forming the ancient flood plain along Brushy Creek already referred to and the other lying at higher levels on the steeper valley sides and now largely eroded. This seems probable, but no recognizable distinction between materials from the two locations was found.

The terrace alluvium is unquestionably younger than the upland gravel remnants, whose materials it incorporates. It is likewise older than the Recent alluvium which overlies it and its soil at many places along Brushy Creek. In similar topographic situations the depth and degree of development of the soil on the terrace alluvium is much more comparable to that of the soil on the residual marls than to that on the Recent alluvium. These considerations suggest that the terrace alluvium is of Pleistocene age and that it corresponds to one or more of the terraces of Brazos River, most of which were formed during that epoch.

It is difficult to imagine that the large quantity of material represented by the terrace alluvium could have been eroded and transported by a stream no larger than the present Brushy Creek. Nevertheless, even allowing for the capture of its headwaters by the Tehuacana drainage system, there is no indication that Brushy Creek ever drained an area much larger than it now drains. It is therefore necessary to assume a much greater volume of stream flow than at present and consequently a much heavier rainfall. These conditions are not inconceivable during the Pleistocene, when great differences in temperature probably existed between the atmosphere over different portions of the earth.

Stenzel (1938, p. 169) noted the remarkable development of terraces along the smaller drainage lines of Leon County. From a study of the meander scars and alluvial fans along the valley of Navasota River, he concluded (pp. 181–184) that that stream also formerly had a much greater volume than at present. He states that the phenomenon is not local but regional.[7]

If the terrace alluvium was deposited by running water it must have resulted from very turbulent run-off. The very local origin of the materials, the heterogeneous mixture of pebbles, lumps of undecayed marl, sand, and clay, and the general absence of stratification can be accounted for by flash floods, rapid erosion, brief transportation, and quick deposition. But the most surprising feature of this alluvial marl is the total absence of anything resembling soil in its composition. The soil now overlying it is a residual soil, formed in place from the terrace alluvium as parent material.

Even if it is assumed that the region was a desert with only intermittent heavy rainfall, some kind of soil should have been present at the time of deposition of the alluvial marl, especially since the parent materials were not quartz and resistant silicates but easily weathered clay and lime mud. This should have been true even if the climate were cold, provided that it was not actually glacial. A possible explanation is that during this time the blacklands had been completely denuded of their soil cover, and that the forces of erosion were acting directly on the decayed and even on the sound residual marl, together with the remnants of the upland gravel. This implies an intensity of erosion far beyond anything taking place under even the most careless agricultural methods of the present day. The terrace deposits may therefore be the record of only the later stages of this erosion, the original soil having been washed completely out of the country. This would also mean that all the present soil of the entire watershed has been formed since the Pleistocene. Although drastic, none of these implications is inconsistent with the great changes in climate and base level which must have occurred during Pleistocene time.

An alternative explanation was first suggested to the writer (Blank) by C. L. Baker (personal communication, May 8, 1942). The heterogeneous nature of the alluvial marl, and the absence of stratification within it, might indicate an origin by soil creep or mass wastage from the sides of the valleys, rather than by deposition by turbulent streams having greater volume than they now possess. This might also explain the very local origin of its constituent materials. The concentration of pebbles found here and there at the base of the alluvial marl might correspond to the stone lines observed by Sharpe (1938, pp. 24–25; *in* Ireland, Sharpe, and Eargle, 1939, pp. 22–23) at the base of the creeping mantle in South Carolina, rather than to the "basal conglomerate" of a sedimentary deposit.

Mass wasting is now going on along the steep banks of Brushy Creek and some of its tributary gullies, but at first thought it would seem that the slopes of the buried Brushy Creek valley in the residual marl, as revealed by borings, are too gentle to permit any large part of the terrace alluvium having been formed in this way. Nevertheless, certain studies of the soils on the watershed suggest that even on these gentle slopes soil creep may be appreciable at the present time. Both the soil and the underlying marl expand and contract

---

[7]The present authors were unacquainted with Dr. Stenzel's work at the time they reached their conclusions regarding Brushy Creek.

considerably with changes in moisture content, and this results in movement of at least the surface layers. When the soil becomes thoroughly saturated after heavy rains it acquires properties resembling those of a viscous liquid, and the alluvial marl can be brought to the same condition artificially without much difficulty. It is possible, therefore, that the entire mantle of soil and underlying marl, down to the depth to which moisture changes occur, may for a long time have been slowly creeping and flowing down the slopes and accumulating in the valleys without any radical dislocation of the normal sequence of decayed marl and its overlying soil horizons taking place during the process. As this material accumulated in the valleys the streams would cut gullies and channels in it and, overtopping these trenches during floods, might level and re-work the valley fill to some extent. But such stream action may actually be the minor factor in the origin of the geologic formation herein called the terrace alluvium.

Recent alluvium.—Recent alluvial deposits, which are still accumulating, occur along most of the streams of the region, from the smallest to the largest, including Brazos River. Along Brushy Creek and its larger tributaries the Recent alluvium occupies a narrow belt along both sides of the channel, which constitutes the area overflowed by the average high water. Deposits resulting from sheet erosion of cultivated fields also are part of the Recent alluvium, and a few of the more prominent of these have been mapped (Pl. I).

The Recent alluvium is well exposed in the banks of Brushy Creek for a short distance above and below road 337. Its unconformable relation to the underlying terrace alluvium and soil may be seen at an outcrop at the first bend of the creek below the southern end of the new channel about 900 feet downstream from gaging station J, and also at a bend at approximate Lat. 31°28′10″, Long. 96°51′15″, about halfway between gaging station J and road 337.

Unlike the terrace alluvium, the Recent alluvium consists largely of soil, mixed with variable amounts of sand and gravel if these materials occur on the drainage area contributing to the deposit. Pieces of chalk from eroded fields, marl from gullies, and gravel from roads are present in some deposits. Consequently on the experimental area this alluvium consists of two main types: a brown, sandy type occurring in the northwestern half of the area and along Brushy Creek to beyond the limits of the project, and a black, clayey type found along the tributary streams draining the southeastern half of the area. The former constitutes the areas of Kaufman and Catalpa soils, the latter of Trinity soil. The sandy type is just beginning to develop a soil profile, thus differing from the profiled residual sandy soils of the region. The black, clayey type, consisting as it does almost entirely of structureless black soil, is very difficult to distinguish from the residual black soils formed on the adjacent Pecan Gap marl or terrace alluvial marl, except where it contains thin laminae of sandier material.

It is noteworthy that the influence of the sandy marls of the Wolfe City member is manifested farther downstream in the Recent than in the terrace alluvium. In keeping with this slower deposition, visible stratification or lamination is more common in the Recent alluvium, although seldom conspicuous.

A maximum thickness of 12 feet of Recent alluvium has been observed along Brushy Creek, and it is probably no thicker than 15 feet anywhere within the experimental area. The broad, gently sloping plain along the creek is built of the Pleistocene terrace alluvium, and although parts of it are occasionally flooded in modern times, these areas bear only a thin veneer (less than 1 foot in most places) of Recent deposits. The bulk of the Recent alluvium occupies the zone between the outer limits of the meanders. Within this zone the stream is now flowing on Recent alluvium, and there probably are filled channels of greater depth, but it is cutting into terrace alluvium and residual marls at most of the outer curves. Although some deposition takes place during every flood, the balance at the present time seems to be in favor of erosion of the channel. This is especially true in the Pecan Gap area, where there is some ground-water flow. Exceptions are found near the junctions of Brushy Creek with its tributaries flowing through gaging stations Y and Z (Pl. I), where deposition seems to have the upper hand.

Decayed Rock and Soils

Decay of the rocks.—The first stage in the decomposition of the marls and chalks of the experimental area seems to be a process of oxidation, which begins at a depth of 20 to 30 feet below the surface. Its only immediate effect is a change in color from bluish black or bluish gray to a gray or tan, frequently mottled with rusty spots or streaks. As the surface is approached differences between different strata become more pronounced, apparently according to their relative iron content. The sandy marls take on a uniform rusty brown, the highly calcareous marls become brownish gray, and the chalks become little darker than a tan.

In the highly calcareous marls fracturing by the formation of curved cracks following conchoidal surfaces is prominent at depths as great as 25 feet. In the sandy marls the fracture pattern is less regular, and in the chalks it may not appear at all. At lesser depths the conchoidal fractures in the highly calcareous marl become more and more abundant until finally the entire material is broken into closely set lumps half an inch or less in diameter. Further chemical decay seems to accompany this process, so that the marl becomes softer and rustier in color, and then passes imperceptibly into the yellowish-gray subsoil and from that into the black top-soil, which may be 3 or 4 feet thick. Within the chalk the fractures are more open but farther apart, and the material retains its hardness to within a few feet of the surface, and then changes rather sharply to a white subsoil and a shallow black top-soil. The sandy marls behave much like the highly calcareous marl, the rusty brown color continuing into the subsoil.

Relation between parent rocks and soils.—A description of the soils of the experimental area and a detailed conservation survey map showing their distribution may be found in Hydrologic Bulletin 5 (Baird, Lauritzen, et al., 1942). A comparison of this map with the geologic map of this paper (Pl. I) will show the intimate relation of the soils to the geology.

A residual soil may be regarded as the result of five principal factors, namely, parent material, climate, vegetation, topography, and length of time through which a particular set of these influences has been operative. For mature soils the cumulative effect of climate often outweighs most of the other factors, thus tending to produce more or less uniformity in all the soils of a particular climatic region. This part of Texas lies just within the zone of the pedalfer soils, that is, the rainfall at the prevailing temperatures is sufficient to remove all the soluble salts, including calcium carbonate, from the soils derived from most geologic materials. The purer marls and chalks of the Cretaceous formations, however, present material which is abnormally rich in calcium carbonate and unusually easily weathered. As a result the prevailing rainfall cannot remove all the calcium carbonate, and calcareous soils (rendzinas) are produced in the pedalfer climatic zone. A slight decrease in the proportion of calcium carbonate in the parent material permits its complete removal from the surface layers of the resulting soil. The introduction of sand from the parent material increases the penetration of the rainfall and promotes the development of definite horizons by differential shifting of some of the finer constituents. Thus comparatively slight changes in the lithology of the underlying sediments are very closely reflected in the residual soils derived from them. Exact correspondence is prevented by the effects of other factors, here chiefly topography as it controls drainage.

As shown on maps in Hydrologic Bulletin 5 (Baird, Lauritzen, et al., 1942), the Houston soils, which are calcareous throughout the profile, form on the chalks and the highly calcareous marls of the Pecan Gap member, as well as on that portion of the alluvial marl which has been derived chiefly from these strata. They are found also on the silty marl of the Wolfe City member in spite of its lower calcium carbonate content, probably because the invisible silt is too fine, and the clay content too high, to permit much internal leaching.

The Houston-Hunt soils are found on the sandy marl of the Wolfe City member. The streaked development of these soils seems to bear no relation to any variation in the lithology of the parent material and is without adequate explanation.

The Crockett soils develop on some parts of the area underlain by the sandy marl of the Wolfe City member. There is some reason to believe that within the experimental area these soils owe their greater degree of leaching to an admixture of sand from ancient alluvial deposits, now almost completely eroded, but the evidence is inconclusive.

Within the project area the Wilson soils are confined almost entirely to those parts of the terrace alluvium derived wholly or chiefly from the Wolfe City strata. They occur also here and there on the flatter parts of the uplands, probably because of poor drainage, where as far as has been determined no alluvium exists.

The Recent alluvium consists largely of transported soil, and the soils now forming on it (Trinity and Catalpa) are in early stages of development. It should be emphasized that almost all the soil on the terrace (older) alluvium has not been transported as soil but has formed in place as residual soil from alluvial parent material.

Concretions and similar bodies.—Concretions are common in the subsoil and in the zone of decayed rock beneath it throughout the experimental watershed. They are related both to the nature of the rock and to the processes of soil formation and are of several types.

Hard, black spheres one-eighth to one-fourth inch in diameter occur extensively in the subsoil on the sandy marl, particularly in the northern part of the watershed where the sand in the marl is coarser and more abundant. Qualitative chemical tests indicate that they consist chiefly of iron and manganese oxides, cementing particles of sand.

Calcium carbonate concretions occur throughout the watershed and are of three principal types:

Small, hard, irregular concretions occur in the subsoil both in the Houston black clay and in the soils of the Wilson series. They are usually brownish or tan and seldom exceed half an inch in diameter. They have an irregular and lumpy surface as if composed of aggregates of smaller individuals.

Smooth, hard, rounded concretions are often found deeper in the subsoil and in the zone of decayed marl in areas underlain by the more highly calcareous marls. They are somewhat softer and whiter than the first type. They are particularly common in the alluvial marl which has been derived from the more calcareous formations.

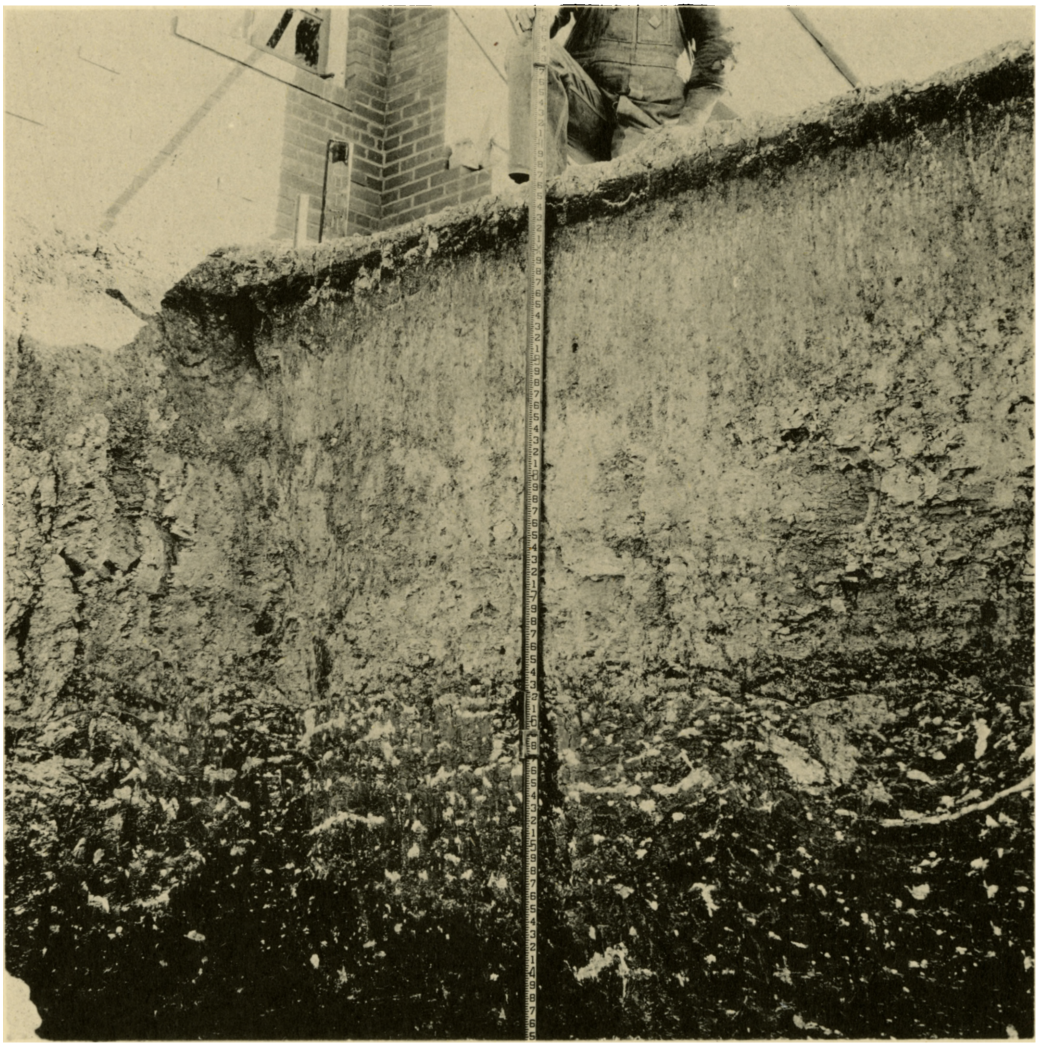
Soft, white, irregular patches of calcium carbonate also are occasionally found in the zone of decayed rock. In places their texture is sufficiently coarse so that individual crystals can be seen with the naked eye. They seem definitely to result from the leaching of calcium carbonate from higher layers by descending waters and its redeposition in crevices and openings below. Thus they are commonly found in the first few feet of the silty marl below the chalk wherever the contact between these strata lies in the zone of oxidation (Pl. III). They partake more of the nature of deposits of caliche than of concretions.

Crystals of gypsum, both loose and in aggregates, are commonly found in the sandy and silty marls throughout the zone of oxidation. The evidence is insufficient to show whether they are the result of soil-forming processes or of the oxidation of marcasite in place.

Analytical Data

In order to investigate the fundamental differences existing between the various strata underlying the project area and to study their relation to the soils and to the ground water, certain chemical, mechanical, and microscopic studies were made upon representative samples selected from the auger holes and excavations.

Two samples were studied from each of the important subdivisions (except the upper chalk and the upper highly calcareous marl) of the Cretaceous strata above described, one of unoxidized material and the other of oxidized material from a location calculated to represent as nearly as possible the same stratigraphic horizon, assuming a strike of N. 20° E. and a dip of 80 feet per mile. In addition one unoxidized sample each was taken from the upper chalk, the glauconitic portion of the lower chalk, and the hard calcareous sandstone, and one sample from each of the two types of terrace alluvium. Material from a single depth or run in a particular hole was used, and from this, undisturbed lumps were selected wherever possible. A thin section was made from one of the lumps



Contact of Pecan Gap chalk (above) with Wolfe City silty marl (dark, below), showing soft white calcium carbonate leached from the chalk and deposited in crevices in the marl. Excavation for settling tank at project laboratory. Soil Conservation Service photographs No. 20,197-A and 20,197-B.

in each sample. The remaining lumps were crushed to about 5-mm size and quartered, and a 50-gram portion was taken for acid treatment. About 10 grams of the remainder of each sample were finely ground for chemical analysis.

The 50.000-gram samples of the air-dried, crushed material were treated with an excess of 1:5 hydrochloric acid at room temperature, allowed to stand overnight, brought to boiling, allowed to settle, filtered, and washed. Because preservation of the glauconite was desired, sample No. 6 was treated with 1:5 acetic acid instead of hydrochloric. The insoluble residues were dried at 100 to 110° C. and weighed, and samples from them were used for the mechanical analyses. The filtrates were diluted to 1500 cc., and one-tenth aliquots, representing 5.000 grams of original material, were used for the determination of acid-soluble sulfate.

The other chemical determinations were made on the finely ground, air-dried, original material. Carbonates and silica were determined as most likely to reveal fundamental differences in composition of the strata. Sulfates and chlorides were investigated because of the presence of the corresponding ions in the ground water in large amounts.

Carbonates were determined by evolution and absorption of CO_2 according to the method of Shaw (1931), except that 1:6 HCl was used instead of 1:9. A separate sample of about 3 grams was fused with sodium carbonate, dissolved in dilute nitric acid, and chlorides determined in this solution as recommended by Hillebrand (1919, pp. 220–221 and 231–232). After removal of the excess silver, the filtrates were evaporated with HCl and the silica determined in this residue and in the residue insoluble in nitric acid by difference after volatilization with HF. Total sulfur was determined as sulfate in the HCl solution after removal of the silica.

Mechanical analyses of the acid-insoluble residues from the original samples were first carried out by the method of Olmstead, Alexander, and Middleton (1930, pp. 14–20) for the mechanical analysis of soils. The "sand" fractions obtained, however, especially from the chalks and highly calcareous marls, consisted largely of silt and clay aggregates, and it was evident that complete dispersion had nowhere nearly been attained. Also, the marcasite in the unoxidized samples caused them to react violently with the hydrogen peroxide used in this method for the removal of the organic matter and to require excessive amounts of this reagent.

The object of the mechanical analyses was primarily to test the conclusions reached in the field regarding the relative amounts of sand in the different strata of the Pecan Gap and the Wolfe City members, and also to obtain sand fractions clean enough for microscopic study of the constituent minerals. Complete separation of clay from the sands was therefore essential. It seemed possible that the incomplete dispersion of the silt and clay might be due to a little gelatinous silicic acid which might have been formed by the acid treatment of the original material. This suggested that sodium carbonate might aid the dispersion. Treatment of some of the insoluble residues with sodium carbonate, followed by decantation and washing, resulted in much cleaner sands. It was also noticed that during the hydrogen peroxide treatment by the standard procedure of Olmstead, Alexander, and Middleton, the evolution of great numbers of minute gas bubbles in the violent reaction with the unoxidized samples helped to break up the aggregates and produced cleaner sand fractions than those from the already oxidized material. As a result of these observations a procedure was devised using both sodium carbonate and the evolution of a gas, even though it was realized that the former might not confine its solvent powers to any finely divided silica which might have been artificially produced.

Attempts were first made to remove the organic matter by extraction with carbon bisulfide.[8] Alcohol was found somewhat more effective, but neither reagent removed the organic matter completely. After drying and reweighing, the sample was shaken with a 10-percent solution of sodium carbonate for 20 to 24 hours, decanted, and washed once by decantation. The residue was then treated with a roughly equimolecular mixture of powdered sodium nitrate and ammonium chloride, with a

[8]Compare Milner (1940, pp. 193–196). A Soxhlet extractor was used instead of the funnels described in this book.

TABLE 2. *Description of Samples Analyzed*

Sample No.	Hole No.	Elevation of ground surface *(feet)*[9]	Depth of sample *(feet)*	Formation and description
1	1000	454	14	Pecan Gap. Calculated to be 116 feet above the base of this formation. Soft chalk. Light blue gray. Unoxidized. No silt or sand visible to naked eye or detectable on chewing.
2	1010	463.2	86.6–89	Pecan Gap. 56.5 to 58.9 feet above base of this formation in this hole. Highly calcareous marl. Blue gray. Unoxidized. No silt or sand visible to naked eye or detectable on chewing.
3	413	488.1	16.7	Pecan Gap. Calculated to be 57 feet above base of this formation. Highly calcareous marl. Gray white and light tan. Oxidized. No silt or sand visible to naked eye or detectable on chewing.
4	1010	463.2	141.2–142.3	Pecan Gap. 3.2 to 4.3 feet above base of this formation in this hole. Chalk. Light blue gray. Unoxidized. No silt or sand visible to naked eye; a little detectable as grit on chewing.
5	666	557.3	24.5–25	Pecan Gap. 3.25 to 3.75 feet above base of this formation in this hole. Chalk. Gray white with rusty streaks. Oxidized. No silt or sand visible to naked eye; traces of grit on chewing.
6	694	506.8	50	Pecan Gap. 0.85 foot above base of this formation in this hole. Glauconitic chalk. Light blue gray, with dark green specks. Unoxidized. No silt or sand visible to naked eye; a little detectable as grit on chewing.
8	1010	463.2	155.8–157.7	Wolfe City. 10.3 to 12.2 feet below base of Pecan Gap in this hole. Silty marl. Blue gray to greenish gray. Unoxidized. No silt or sand visible to naked eye; much fine grit on chewing.
9	TW-1	522.5	15.7	Wolfe City. Calculated to be about 15 feet below base of Pecan Gap. Silty marl. Brownish gray to pale rusty. Oxidized. No silt or sand visible to naked eye; much fine grit on chewing.
13	1011	526.4	113.8–116.1	Wolfe City. 95.6 to 97.9 feet below base of Pecan Gap in this hole. Sandy marl. Blue gray. Unoxidized. Sand visible to naked eye.
14	256	553.6	10.7	Wolfe City. Calculated to be 95 feet below base of Pecan Gap. Sandy marl. Brownish gray to pale rusty. Oxidized. Sand visible to naked eye.
17	1011	526.4	161.8–163.5	Wolfe City. 143.6 to 145.3 feet below base of Pecan Gap in this hole. Sandy marl with sandstone lenses. Blue gray. Unoxidized. Sand visible to naked eye; contains pieces of hard calcareous sandstone also.
18	807	542.6	11	Wolfe City. Calculated to be 144 feet below base of Pecan Gap. Sandy marl with sandstone lenses. Brownish gray to rusty. Oxidized. Sand visible to naked eye; contains pieces of hard calcareous sandstone also.
19	1011	526.4	182.4–183.7	Wolfe City. 164.2 to 165.5 feet below base of Pecan Gap in this hole. Hard calcareous sandstone. Grayish blue. Unoxidized. Visible sand firmly cemented with crystalline carbonate.
20	Reservoir Test Pit 3	511.7	6.3–7.6	Terrace alluvium. Overlies highly calcareous marl of Pecan Gap. Alluvial marl, highly calcareous type. Gray with rusty and black spots. Oxidized. Sand generally not visible; very gritty on chewing; occasional pebbles.
21	Soils Pit 10	507 (est.)	11.7	Terrace alluvium. Overlies sandy marl of Wolfe City. Alluvial marl, fine sandy type. Variegated gray and pale rusty. Oxidized. Sand just visible to naked eye; very gritty on chewing; no pebbles.

[9]Elevations for ground surface are in feet above mean sea level and unless otherwise stated were determined by levelling from bench marks based upon the U. S. Coast and Geodetic Survey B. M. near the railroad station at Riesel, Texas.

TABLE 3

Partial chemical analyses of rock materials. Analyzed by H. R. Blank and N. L. Stoltenberg.

Sample No.	Total SiO_2	CO_2	Moisture[a] at 100–110° C.	Residue insoluble in 1:5 HCl	$CaCO_3$ = CO_2 (calc.)	SO_4 soluble in 1:5 HCl	Total Cl	Total S	Sulfur = soluble SO_4 (calc.)	sulfide S (calc.)
1	15.39	31.55	1.71	13.37	71.75	0.078	0.024	0.340	0.026	0.314
2	30.46	19.46	4.05	47.53	44.25	0.190	0.040	0.734	0.064	0.670
3	26.23	23.06	2.98	38.84	52.44	0.010	0.048	0.040	0.003	0.037
4	15.80	32.13	1.45	22.14	73.06	0.105	0.069	0.373	0.035	0.338
5	11.65	33.95	1.66	16.80	77.21	0.031	0.013	0.044	0.010	0.034
6	11.90	33.59	1.54	20.99[b]	76.38	0.142	0.066	0.469	0.047	0.422
8	48.91	6.56	5.36	72.95	14.92	0.229	0.120	1.063	0.076	0.987
9	49.76	10.39	4.33	64.91	23.64	0.018	0.064	0.066	0.006	0.060
13	63.24	3.14	3.53	81.86	7.14	0.231	0.171	0.805	0.077	0.728
14	60.87	2.56	4.64	80.45	5.83	0.029	0.036	0.064	0.010	0.054
17	60.48	3.13	3.37	81.98	7.11	0.235	0.050	0.790	0.078	0.712
18	61.72	5.90	2.72	75.28	13.42	0.137	0.162	0.139	0.046	0.093
19	59.18	14.78	0.88	61.58	33.61	0.031	0.051	0.283	0.010	0.273
20	33.70	21.48	3.34	43.09	48.86	0.078	0.119	0.081	0.026	0.055
21	61.41	5.50	4.22	74.67	12.51	0.039	0.112	0.139	0.013	0.126

[a]All percentages calculated on weight of air-dried sample.
[b]1:5 acetic acid used instead of hydrochloric.

TABLE 4

Mechanical analyses of insoluble residues from acid treatment of rock materials.
(A. J. Stewart, Jr., and J. E. Poag, analysts)

Sample No.	Moisture[a] at 100–110° C.	Organic matter by CS_2 and alcohol	Fine gravel (>1 mm)	Coarse sand (<1 mm >0.5 mm)	Medium sand (<0.5 mm >0.25 mm)	Fine sand (<0.25 mm >0.1 mm)	Very fine sand (<0.1 mm >0.05 mm)	Silt (<0.05 mm >0.002 mm)	Clay (<0.002 mm)	Screening loss[b]	Total
1	8.46	1.22	None	0.03	0.15	0.33	0.28	14.68	56.72	0.07	81.94
2	7.04	0.28	Trace[c]	None	Trace	0.02	0.06	19.37	65.19	None	91.96
3	8.28	0.24	None	None	Trace	0.03	0.09	16.03	65.64	0.02	90.33
4	6.08	0.76	None	Trace	Trace	0.19	6.84	29.54	48.81	0.15	92.37
5	8.14	0.61	None	Trace	Trace	0.26	1.43	24.97	56.19	0.08	91.68
6	7.08	0.54	0.03[d]	0.08	0.32	2.42	5.07	23.88	48.41	(–.03)[e]	87.80
8	6.75	0.38	None	Trace	Trace	0.03	0.12	32.12	50.95	0.04	90.39
9	5.61	0.30	None	None	Trace	0.05	1.57	45.05	40.34	0.12	93.04
13	4.26	0.48	None	None	Trace	5.70	24.53	25.46	31.71	0.12	92.26
14	5.60	0.26	None	None	Trace	2.96	16.01	28.71	36.54	0.10	90.18
17	5.56	0.89	None	None	Trace	0.73	12.64	35.18	34.30	0.14	89.44
18	5.34	0.59	None	Trace	0.08	14.13	16.73	23.54	30.83	0.20	91.44
19	1.34	0.57	None	0.05	1.06	65.25	9.49	10.40	9.34	0.21	97.71
20	8.99	0.59	2.85[f]	1.81	4.87	6.91	3.40	18.47	41.05	0.15	89.09
21	6.87	0.53	0.27	0.47	0.72	2.64	10.66	35.91	31.75	0.16	89.98

[a]All percentages calculated on weight of air-dried sample of insoluble residues.
[b]Screening loss equals difference between weight of total sands before screening and sum of weights of all sand and silt fractions obtained by screening.
[c]Trace equals less than 0.01 percent.
[d]Most of the coarser material in this sample is glauconite. Acetic acid was used in obtaining the insoluble residue.
[e]Sum of weights of fractions was greater than weight before screening in this case; this percentage is therefore subtracted in totalling column.
[f]Pebbles from 5 to 10 mm in diameter were found in the original material but were purposely crushed in quartering the sample before acid treatment and chemical analysis.

very little water, and warmed, which produced a frothy evolution of nitrogen and assisted the dispersion without creating an oxidizing environment. A portion of the decanted sodium carbonate solution was then returned to the mixture, and the material was shaken again for 20 to 24 hours and then filtered through a porous cylinder (Pasteur-Chamberland filter) and washed with water. The dark brown color of many of the filtrates indicated that considerable additional organic matter was removed by the sodium carbonate.

As the sample dispersed on washing it began to clog the filter, and it was soon evident that all the soluble salts could not be removed in this way. The material was therefore washed off the filter into an electro-dialysis apparatus and dialyzed, with frequent changes of water, until the liquid gave no test for chlorides and was not alkaline to phenolphthalein.

Upon removal of the sample from the dialysis apparatus it was observed that the clay, flocculated by the electrolysis, dispersed very incompletely in a small volume of water, but that after diluting to between one and two liters dispersion readily took place. The suspension was then allowed to stand overnight, a period more than sufficient, as calculated from Stokes's law, for all the silt to settle in the depth of liquid used. The cloudy supernatant liquid was then carefully siphoned off, and the process was repeated until most of the clay had been removed. In the residue the sands, silt, and remaining clay were separated and determined by the standard procedure of Olmstead, Alexander, and Middleton above referred to, except that no sodium oxalate was added, no metallic ions being present. The clay which had been siphoned off was flocculated by electrolysis, dried, and weighed.

It is believed that the method used gives a much truer estimate of the actual sand content of the insoluble residues than the standard procedure at first tried, but, as may be seen from table 4, it involves a loss of about 10 percent of the material (in one case as much as 18 percent). Weighing the samples at any point between the first dispersion and the final determinations was avoided because of the effect of drying in flocculating the clay, but separate tests indicated that solution by the sodium carbonate was responsible for most of the loss. In addition to any possible gelatinous silicic acid, the sodium carbonate may have attacked the fine silt as well as the clay and the organic matter. Unfortunately neither time nor material was available for more complete investigation of the minimum strength of sodium carbonate required to effect complete dispersion of the insoluble residues, either with or without the aid of the evolution of nitrogen, and of the extent to which solution would take place at that minimum concentration.

Microscopic examination showed the sand and silt grains in most of the fractions to be very clean. Silt aggregates, and even grains of clay minerals of silt size, were still numerous in the coarser fractions of samples nos. 4, 5, and 17, and glauconite aggregates in no. 6. Most of the marcasite abundant in the unoxidized samples came through unscathed.

Throughout the analyses much difficulty was caused by the hygroscopic nature of the material and its tendency to adjust its moisture content to that of the atmosphere. Weights after successive dryings were never the same, but the variation could be brought to within less than 0.05 percent during a period of steady dry weather. Even on the finely ground original rocks, samples for the different determinations had to be weighed out on the same day in order to be strictly comparable.

Incomplete as the analyses are, they indicate some interesting generalizations. The extreme fineness of practically all the rock material in the experimental area, especially in the highly calcareous marl, is shown by the mechanical analyses, which thus confirm the conclusions drawn in the field by chewing tests. It is noteworthy, however, that all samples contain large amounts of silt as well as clay. The chemical determinations show the more calcareous nature of the Pecan Gap member as compared with the Wolfe City member. The upper chalk is very similar in composition to the lower, although in appearance the material of the sample closely resembles the highly calcareous marl.

The local origin of the alluvial marls is well shown by their resemblance in both chemical and mechanical composition to

Contact of Pecan Gap chalk (center) with Wolfe City silty marl (below). Chalk overlain by alluvium. Big Sandy Creek, three-fourths of a mile north of St. Paul's Church, Falls County, Texas (loc. 6, Pl. II). Soil Conservation Service photograph No. 20,566.

the residual strata in the vicinity, and the calcareous and sandy types are sharply differentiated. In both types, however, their alluvial origin is indicated by the wider distribution of sand sizes.

The sandiness of sample no. 6 is due largely to glauconite.

The high content of silt and clay, together with absence of coarser sand, shown by samples no. 8 and 9, agrees with the properties of this zone of silty marl at the top of the Wolfe City member.

Much of the ground water of the project area is known to be high in sulfates and chlorides. Since gypsum crystals have been observed at many places in the strata in the zone of oxidation, especially in the Wolfe City member, it was thought that the analyses might show a rather wide distribution of soluble sulfates in this zone, although visible gypsum was avoided in selecting the samples. However, the analyses indicate rather clearly that the oxidized zone has been leached rather than enriched in chlorides and sulfates, and that the marcasite and possible connate water in the unoxidized marls and chalks are the ultimate sources of these soluble materials.

Structural Features

In conformity with the general structure of the Gulf Coastal Plain, the Cretaceous strata on the experimental watershed dip toward the Gulf of Mexico at angles a little greater than the general slope of the land surface, and their belts of outcrop therefore turn toward the southeast whereever the land is lower and toward the northwest where it is higher (Pl. I). This has been ascertained in a general way for the Cretaceous rock types above described by numerous auger holes bored throughout the area to shallow depths. The exact attitude of the beds has been much more difficult to determine because of the impossibility of identifying individual strata. No key beds identifiable in different parts of the experimental area have been found, except the lower chalk of the Pecan Gap member. The upper edge of this is indefinite, and only its lower edge, its contact with the underlying silty marl, can be readily identified at all places.

This contact between the Pecan Gap member above and the Wolfe City member below is stated to be an unconformity in northeast Texas by Stephenson (1918, p. 156; 1929, p. 1330) and by Ellisor and Teagle (1934, pp. 1517 and 1528). The latter authors apparently believed this break to be of wider geographic extent.

Certain evidence from the experimental watershed tends to confirm this view. As already noted, glauconite was found in the lowermost 1 or 2 feet of chalk in all exposures, except where it might easily have been removed by oxidation. In hole 1010, just southeast of the experimental area, and in hole 1020 on Brazos River, where the contact was cut in unoxidized material, fragments of silty marl were found in the lowermost few inches of chalk. Cylindrical bodies of chalk extended down for as much as 16 inches into the underlying silty marl and probably represent filled burrows of marine animals.

On the other hand, both in these holes and at the outcrops on Big Sandy Creek (Pl. IV), lenses of glauconitic chalk were found in the uppermost foot of the silty marl and are not easy to explain unless the contact is somewhat transitional. In hole 694, near the extreme southern end of the experimental area, lenses and streaks of silty marl were first encountered at depth 42 feet. With increasing depth these gave way to chalk again, and another and sharper contact with the silty marl was found at depth 51 feet. But at all other places the change from chalk to silty marl was found entirely complete within 2 feet, and at most places within 6 inches.

It thus appears that the one and only identifiable stratigraphic marker on the experimental area probably represents an unconformity and therefore a surface which would be expected to be irregular as the result of erosion, whether submarine or subaerial. Before this was realized the dip and strike of this contact were determined by calculations from a large number of borings, assuming it to be a plane and determining its position from the location and elevation of any three known points. The results, while not entirely harmonious, were sufficiently so to indicate that at least in this vicinity this surface strikes between N. 10° E. and N. 20° E. and dips east by south at about 80 feet to the mile, and that it probably departs but little from the actual strike and dip of the strata.

All the alluvial deposits described above are unconformable with the Cretaceous strata and with each other.

Minor faults are present at many places throughout the experimental area, but there is no evidence that any of them have affected the geologic structure to any great extent. Those shown in Plate I were indicated from surveys of the chalk-silty marl contact, irregular results in the calculated dip, and the presence of unusual amounts of ground water, but in none of them could the displacement exceed 10 feet, and it is probably much less. Because of the known presence of minor faults and the alignment of some of the tributary valleys, search was made for some displacement of greater magnitude, but no evidence of any such was found, and the drainage pattern is best attributed to differential erosion along the strike of the harder and softer beds.

Minor faults can best be seen in the outcrops of chalk because of the brittleness of this material, but they undoubtedly occur also in the highly calcareous marl, and probably in the sandy marl as well. In the more brittle materials the faulting leaves open spaces which become filled with calcite, flat pieces of which appear in the overlying residual soil. On these pieces casts of the slickensides are often preserved. In the marls, because of their more elastic nature, fault movements are usually recorded only as narrow, closed joints along which a little oxidation and decay have taken place, often indicated by a rusty stain. Joints probably resulting from similar but still more minor disturbances are found in the chalk and in the harder portions of the marl. In the chalk some of these remain open and become channels for the circulation of ground water.

The characteristic conchoidal fracture of the marl and most of the fractures in the chalk seem to be more the result of weathering than of earth movements and to be due in large measure to an expansion and contraction connected with different degrees of hydration. Marl brought up from the unoxidized zone checks and crumbles when exposed to the air, apparently because of shrinkage from loss of moisture. The surface soil in the blacklands exhibits this change in volume with change in moisture content to a remarkable degree, so that in dry weather deep cracks up to several inches wide form in all areas of undisturbed soil. It would appear, then, that the zone of oxidation represents the total thickness of the rock and soil affected by seasonal changes in moisture content, and that below this zone the only joints present are those due to earth movements. This view is supported by other evidence indicating that the ground water is almost entirely confined to the cracks and joints of the zone of oxidation and that, at least in the chalk and the highly calcareous marl, free water is entirely absent at greater depths. The distribution of the ground water therefore may be both the result and the cause of the manner of weathering of the rock.

PECAN GAP CHALKS IN THE ADJACENT REGIONS

The various members of the Taylor marl in central Texas are discussed by Adkins in "The Geology of Texas" (1933, pp. 463–467). These include, in McLennan and Falls counties, a basal highly calcareous marl just above the Austin chalk (Burditt marl), overlain by a sandy marl which south of Brazos River has been called the Durango sand by Dane and Stephenson (1928). North of the Brazos a sandy marl appears a little higher in the section and has been regarded by the same authors as a southern extension of the Wolfe City sand. This is the sandy marl occurring on the watershed area. On the east side of the Brazos, at Marlin and extending from there north-northeastward through Falls, McLennan, and Limestone counties, several chalk outcrops have been included in the Marlin chalk by Dane and Stephenson. Above these chalk strata the section consists of marl to the base of the Navarro group. South of the Brazos in central Falls County a similar chalk was named the Lott chalk by Dane and Stephenson, and still farther south the Rogers chalk of Adkins and Arick (1930, pp. 65–66) occurs in Bell County.

Ellisor and Teagle (1934) correlated all these chalks with the Pecan Gap chalk of east Texas on the basis of their foraminifera, and the names Lott and Marlin were subsequently abandoned by the U. S. Geological Survey. Ellisor and Teagle discuss the unconformity and the change in the microfauna between the Pecan Gap member and the underlying Wolfe City member and state that no similar break in the microfauna occurs between this contact and the basal part of the Nacatoch sand of the Navarro group. Dane and Stephenson, however, believed the Marlin chalk on a lithologic basis to be only about 50 feet thick and to be overlain by 250 feet or more of upper Taylor marl.

The geologic map of Texas (Darton et al., 1937) shows a continuous strip of Pecan Gap chalk from Red River County to south of Colorado River. It is shown as about three-fourths of a mile wide in southeastern McLennan County and as passing just west of Mart and crossing the McLennan-Falls County line along the valley of Big Creek.

The contact between the lower chalk and the underlying silty marl, which passes through the experimental watershed, has been traced by the present authors from Big Creek to Brazos River. That this lithologic change corresponds to the microfaunal change from the Wolfe City member to the Pecan Gap member is indicated by the determinations of the microscopic fossils in samples from holes 1010 and 1011, given in the appendix, which were made at the laboratory of the Humble Oil and Refining Company at Houston, Texas, through the courtesy of Messrs. John Teagle and F. W. Rolshausen.

This Pecan Gap—Wolfe City contact is shown by a line on Plate II. Between outcrops the contact was traced by means of seeps, crawfish holes, and the character of the subsoil at eroded spots. Dashed portions of the line indicate uncertainty in its location and for the most part represent places where the Cretaceous rocks are obscured by alluvium.

The contact crosses Big Creek between the Riesel-Mart road and the Waco-Mart highway about 1 mile west-southwest of Mart and thence runs in a general south-southwesterly direction about 2 miles northwest of the position shown on the geologic map of Texas. As would be expected from its strike of about N. 20° E. and its east-southeastward dip, it swings to the east of this general trend where it descends into the valleys of Little Brushy, Brushy, and Big Sandy creeks, and turns sharply westward to climb the intervening ridges. In the Brazos River bottoms the contact is completely buried by alluvium, but it must cross the river near a sharp bend just below the mouth of Perry Creek and a little over a mile upstream from the traditional "Falls of the Brazos."

The Pecan Gap—Wolfe City contact is not actually exposed in Big Creek, but chalk occurs in a small gully on the west side of the creek at locality 1, Plate II, and silty marl crops out on the right bank about 500 feet upstream. In a small tributary at locality 2 a ledge of the basal chalk is exposed, and by very shallow digging the silty marl may be seen beneath it. A boring (hole 1001) at this point confirmed the surficial evidence. Glauconitic chalk crops out in the roadside gully at locality 3. The chalk-silty marl contact was cut in digging the new channel for Brushy Creek below gaging station G on the experimental watershed (Pl. I). Two outcrops of the hard chalk (but not the basal glauconitic bed) occur on the left bank just below this point (loc. 4, Pl. II), and the transition to highly calcareous marl is well shown in the succeeding outcrops, at and downstream from spring well 26 (Pl. I). Chalky subsoil and underlying ledge are exposed in the eroded farmyard at locality 5 (Pl. II), where a Pecan Gap outlier caps the hill.

Three excellent exposures of the chalk-silty marl contact occur on Big Sandy Creek three-fourths of a mile north of the gravel road passing St. Paul's Church and about the same distance east of the Waco-Marlin highway, State highway No. 6 (loc. 6, Pl. II; Pl. IV). In these outcrops, as in holes 1010 and 1020, lenses of glauconitic chalk as well as filled burrows are found in the underlying marl. Lower beds of the silty marl crop out on meanders of both branches of the creek just above their junction. Farther downstream the hard, non-glauconitic chalk and its transition into highly calcareous marl are well shown in a series of outcrops.

The uppermost silty marl beds are exposed in a deep gully at locality 7. Chalk may be found by shallow digging in the sides of the channel just above the head of the gully. Lower beds of the Wolfe City crop out in roadside gullies at localities 8, 9, and 10.

A steep-sided valley makes a deep re-entrant into the chalk at locality 11. A ledge of the basal chalk, glauconitic in its lower part, forms a small waterfall (at times of run-off) near the head of this valley. Silty marl is washed up from the pool below and crops out in the banks farther down the channel.

A better, although small, exposure of the actual contact may be found in the gully on the east side of the road at locality 12. The basal glauconitic chalk appears again at a small spring east of the road on the southeast side of this same valley, while the uppermost silty marl beds crop out in a cut bank farther downstream west of the road. Where this same road crosses the next small tributary toward the south (locality 13), hard white chalk is prominent in the road ditches on both sides of the valley, but the basal beds are not exposed. This is apparently the locality mentioned by Ellisor and Teagle as about 2 miles north of Marlin.

From this point southward the Pecan Gap—Wolfe City contact is very difficult to follow because it is almost everywhere concealed by the terraces and flood plain of Brazos River. The difficulty is increased by lithologic changes within the Pecan Gap. It appears that the highly calcareous marl found on the experimental watershed becomes slightly silty in the vicinity of Marlin, although much less so than the underlying Wolfe City beds. Also the higher chalk beds become harder, thicker, and more resistant to erosion and consequently more prominent in outcrop.

From locality 12 southward the contact apparently follows the east side of the same small stream valley to the edge of the Brazos bottoms, where it turns southeastward for a short distance along the edge of the hills. Its presence is indicated only by seeps, which in view of the presence of some gravelly alluvium are somewhat uncertain criteria. In the bottom of a long-abandoned gravel excavation at locality 14, crawfish have brought up very silty marl of the Wolfe City, and similar material occurs in a poor outcrop on the west side of the next valley to the east (locality 15). Chalk appears at locality 16 on the east side of this same valley and highly calcareous marl at 17 in the next small valley eastward. It seems therefore that the contact disappears beneath the alluvium of the bottom-lands in this vicinity.

Hard, white chalk, becoming blue gray at shallow depth, crops out in the bed of Brazos River at the lower of two sharp bends just below the mouth of Perry Creek (loc. 18, Pl. II). Hole 1020, a pit dug in the chalk at this location, penetrated the Pecan Gap—Wolfe City contact at depth 14 feet (elevation approximately 307). Downstream from this point highly calcareous marl crops out in the river bed at intervals for about a mile, becoming harder and chalkier again at the traditional "Falls of the Brazos" (loc. 19, Pl. II), where the ford is located.

It would appear therefore that most of the other chalk outcrops in this region mentioned in the literature belong considerably above the base of the Pecan Gap member and are stratigraphically higher than the principal chalk bed crossing the experimental watershed. Assuming a strike of N. 20° E. and a dip of 80 feet per mile, and in the absence of any evidence of repetition of strata, the outcrop (loc. 20, Pl. II; elevation 479 to 485) described by Ellisor and Teagle on Big Creek just south of the Riesel-Mart road would represent a stratum just a few feet higher than the hard chalk on the experimental area, or between 11 and 19 feet above the base of the Pecan Gap. The chalk described by Dane and Stephenson on Big Creek just south of the McLennan-Falls County line (locality 21, elevation approximately 463) would be about 140 feet above the base of this member. In hole 1010 (locality 22) the "upper chalk" of the southeastern part of the experimental area was encountered from elevation 434 to 447, which is 116 to 129 feet above the base of the Pecan Gap.

Ellisor and Teagle select as the type locality for the *Diploschiza cretacea* zone of the Pecan Gap member an outcrop at locality 23, about 1 mile east of Lamar School (called Harmony Hill on some older maps). Here the rock is not very hard and corresponds more nearly to what the present authors have called "intermediate" between chalk and marl on the experimental area. At approximate elevation 416, this outcrop would be about 90 feet above the base of the Pecan Gap.

Dane and Stephenson's type locality for the Marlin chalk is on the bluffs facing the

Brazos bottoms 0.4 and 0.9 mile south of the court-house at Marlin. Between 30 and 40 feet of chalk are exposed in a deep, branching gully near the bend of McCullough Slough (loc. 24, Pl. II). A thin shell breccia about 3 feet above the lowest chalk exposed is at approximate elevation 341, which would be about 112 feet above the base of the Pecan Gap. The chalk at the "Falls of the Brazos," about 2 miles farther south, should be a little lower in the section because of its slightly lower elevation.

It thus appears that in this vicinity the Pecan Gap member consists of the following:

(a) A continuous zone of hard chalk at the base, 10 to 20 feet thick, resting with slight unconformity on the silty marl of the Wolfe City member. The lowest foot or so of chalk is often softer, contains a little silt, and is everywhere glauconitic. This is transitional upward into:

(b) Ninety or more feet of highly calcareous marl, almost entirely free from detectable silt except in the vicinity of Marlin.

(c) A discontinuous zone of chalk, softer than the lower chalk, from 10 to 40 feet thick, and probably not everywhere at exactly the same stratigraphic horizon. This is transitional into the highly calcareous marl both above and below and probably laterally as well.

(d) Additional highly calcareous marl, of undetermined thickness, extending to an undefined contact with the "Marlbrook marl" or with the Navarro group.

Ellisor and Teagle divide the Pecan Gap into three faunal zones, chiefly on the basis of the foraminifera, and state that the lowest zone is absent in the latitude of McLennan County and that in this region the middle or *Diploschiza cretacea* zone forms the base of the member. They mention that in Falls County the chalk outcrop has a more or less uniform width of 1.5 to 2 miles, and that in that outcrop *Diploschiza cretacea* is found near the top of the chalk and *Pycnodonte vesicularis* toward the base.

Except for the determinations on samples from holes 1010 and 1011, given in the appendix, no micropaleontological work has been done in connection with the present work, and nothing is known of the distribution of foraminifera in the lithologic subdivisions above proposed. However, in all the outcrops and borings studied on the experimental area, only one or two of the fossils found might possibly have been *Diploschiza cretacea minor*. This species is present abundantly in the outcrops south of Marlin (locality 24) and sparingly in the outcrops on Big Creek near Mart (locality 20) and also near the county line (locality 21). It may also be found in the outcrops on Brushy and Little Brushy creeks just below hole 1010.

Pycnodonte vesicularis has rarely been found in place by the present authors, but it is present in the terrace alluvium immediately overlying the chalk and marl along Big Creek near the county line (locality 21). A large flat variety similar to that figured by Dane (1929, Pl. XVIII, p. 94) was found here. A smooth convex variety similar to that shown in Dane's Plate XI, page 66,[10] is common in the banks and channels of both Brushy and Little Brushy creeks in the vicinity of hole 1010. Specimens with various degrees of wing development were also found at this locality. Shells of *Pycnodonte* are also common in the channel of the tributary which enters Brushy Creek from the west just below gaging station J (Pl. I). On the main stream they were not found north of locality 25 (Pl. II). This is just below the mouth of another tributary from the west draining a hill on which the upper chalk stratum occurs.

Shells of *Pycnodonte* were also found at an outcrop of highly calcareous marl in a gully directly in front of St. Paul's School (loc. 26, Pl. II). This is at approximate elevation 439 and should be about 105 feet above the base of the Pecan Gap.

No *Pycnodonte* shells have been found in any outcrops or borings in the lower chalk, that is, the principal chalk stratum on the experimental watershed, nor in any of the stream channels where they cut through these beds.

It therefore seems that *Diploschiza cretacea minor* is common in the upper chalk but very rare below this zone. This is in accord with Stephenson's statement (1934, p. 275) that "this variety is confined to a zone which in general is 30 or 40 feet thick,

[10]This is described as *Gryphaea convexa* (Say) by Stephenson (1937, p. 144).

and probably does not exceed a thickness of 100 feet." *Pycnodonte vesicularis* is also common in the upper chalk but absent below a horizon at least 75 feet above the base of the Pecan Gap member in this vicinity. On the other hand, *Exogyra ponderosa*, common in the lower chalk, is rare in the upper, whereas *Inocerami* are common to both. *Baculites* are abundant at the very base of the lower chalk but have not been observed in the upper by the present authors. The single specimen of *Echinocorys* cf. *E. texana* (Cragin)[11] found by the authors was in place in the upper chalk at locality 21 on Big Creek.

That the two chalks are not merely the result of repetition of strata due to faulting is well demonstrated by the log of hole 1010 (see appendix). Minor faults do occur on the experimental watershed, but their displacement must be only a few feet. A group of faults apparently of somewhat greater magnitude occurs in the chalk cropping out in Brazos River near hole 1020. The most prominent ones are indicated in Plate II. The slickensides suggest that they are downthrown on their east side, but the evidence is not very clear. A downthrow on the west might be expected to cause a repetition of the Wolfe City beds in the river, but as already mentioned this does not occur. The displacement of the faults cannot be very great, because the stratigraphic intervals between the base of the Pecan Gap member and the outcrops of the upper chalk, discussed above, which were calculated without considering any displacement, agree within the error of the elevations, which were determined with an aneroid barometer.

It would seem probable that both the upper and the lower chalk zones should be present also in that part of Falls County southwest of Brazos River. The broadening of the Pecan Gap belt of outcrop shown in that region on the geologic map of Texas appears too great to be merely the result of the repetition by faulting of the comparatively narrow belt shown north of the river, which, as is evident from the foregoing discussion, represents little more than the upper chalk zone.

At the time this paper was originally prepared (1942) no work had been done by the authors south of the Brazos, but brief explorations by the senior author in the autumn of 1944 showed that both the lower and upper chalk zones are present in the region southeast of Lott. The Pecan Gap—Wolfe City contact was found at a small outcrop in a roadside gully 2¼ miles east-southeast from the railroad station at Lott. Here hard, weathered, glauconitic chalk overlies the typical Wolfe City silty marl. As at other localities, the uppermost marl contains lenses of chalk.

Two miles east by south from this locality, hard white chalk is extensively exposed in the channels and banks of Pool Creek and Bell Branch, both above and below their junction. The writer (Blank) found *Diploschiza* fairly common here, as reported by Ellisor and Teagle. A few *Pycnodonte* were also found but no *Exogyra ponderosa*. These outcrops evidently represent the upper chalk.

On the Westphalia-Lott highway 1⅜ miles northeast by north from Westphalia, weathered chalk crops out in the road ditches, and typical Wolfe City silty marl appears in a deep gully a few hundred yards northeast of and down-hill from the chalk. The actual contact was not found.

Three and one-quarter miles east-northeast from Westphalia, hard white chalk crops out in a gully at a road bridge over Pond Creek. *Exogyra ponderosa* shells were found in this chalk, and it apparently belongs to the lower zone.

As in the vicinity of Marlin, in this region the highly calcareous marl between the two chalks appears to contain appreciable silt, which renders its identification difficult in isolated outcrops. Tracing of the Pecan Gap—Wolfe City boundary and of the two chalk zones in this part of Falls County is also impeded by the Brazos River terraces and by faulting, but there seems little doubt that both upper and lower chalks are well represented.

The present authors have not completely traced the chalk—silty marl contact northeastward from the area shown in Plate II, but numerous observations between Big Creek and Navasota River indicate that in this region the Pecan Gap—Wolfe City boundary follows fairly closely the position shown on the geologic map of Texas.

Since this paper was originally prepared (1942), Rouse (1944) has described the Pecan Gap—Wolfe City contact in north-

[11]Figured by Dane (1929, Pl. XV, p. 86).

east Texas. In that region he found *Exogyra ponderosa* abundant in the Wolfe City but not in the Pecan Gap. He states that from Collin County to Red River County, where the chalk disappears, the basal zone of the Pecan Gap is characterized by black phosphatic pebbles, phosphatized *Baculites* and other fossils, and commonly glauconite. The present authors have not found the phosphate pebbles at this contact in McLennan and Falls counties. However, Rouse's observation that "at all good exposures of the contact, chalk-filled borings extend down into the underlying Wolfe City formation" applies equally well to the exposures herein described.

REFERENCES

ADKINS, W. S. (1933) The Mesozoic systems in Texas, *in* The geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232, Aug. 22, 1932, pp. 239–518.

————————, and ARICK, M. B. (1930) Geology of Bell County, Texas: Univ. Texas Bull. 3016, 92 pp.

BAIRD, R. W., JENKINS, D. S., and others (1942) Hydrologic data: Blacklands Experimental Watershed, Waco, Texas, 1937–1939: U. S. Dept. Agr. Hydrologic Bull. 2, 197 pp.

BAIRD, R. W., LAURITZEN, C. W., and others (1942) The agriculture, soils, geology, and topography of the Blacklands Experimental Watershed, Waco, Texas: U. S. Dept. Agr. Hydrologic Bull. 5, 38 pp.

DANE, C. H. (1929) Upper Cretaceous formations of southwestern Arkansas: Arkansas Geol. Surv., Bull. 1, 215 pp.

————————, and STEPHENSON, L. W. (1928) Notes on the Taylor and Navarro formations in east-central Texas: Bull. Amer. Assoc. Petr. Geol., vol. 12, pp. 41–58.

DARTON, N. H., STEPHENSON, L. W., and GARDNER, JULIA (1937) Geologic map of Texas, U. S. Geol. Survey.

DEUSSEN, ALEXANDER (1924) Geology of the Coastal Plain of Texas west of Brazos River: U. S. Geol. Survey Prof. Paper 126, 139 pp.

ELLISOR, A. C., and TEAGLE, JOHN (1934) Correlation of Pecan Gap chalk in Texas: Bull. Amer. Assoc. Petr. Geol., vol. 18, pp. 1506–1536.

HILL, R. T. (1901) Geography and geology of the Black and Grand Prairies, Texas: U. S. Geol. Survey 21st Ann. Rept., pt. 7, pp. 1–666.

HILLEBRAND, W. F. (1919) The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 700, 285 pp.

IRELAND, H. A., SHARPE, C. F. S., and EARGLE, D. H. (1939) Principles of gully erosion in the Piedmont of South Carolina: U. S. Dept. Agr. Tech. Bull. 633, 142 pp.

MILNER, H. B. (1940) Sedimentary petrography, 3d ed., Thos. Murby & Co., London, 666 pp.

OLMSTEAD, L. B., ALEXANDER, L. T., and MIDDLETON, H. E. (1930) A pipette method of mechanical analysis of soils based on improved dispersion procedure: U. S. Dept. Agr. Tech. Bull. 170, 22 pp.

PLUMMER, F. B. (1933) Cenozoic systems in Texas, *in* The geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232, Aug. 22, 1932, pp. 519–818.

POTTER, W. D., and BLANK, H. R. (1939) Blacklands Experimental Watershed ground-water graphs, 1936–1937: U. S. Dept. Agr. SCS-TP-24.

ROUSE, J. T. (1944) Correlation of the Pecan Gap, Wolfe City, and Annona formations in east Texas: Bull. Amer. Assoc. Petr. Geol., vol. 28, pp. 522–530.

SAYRE, A. N. (1936) Geology and ground-water resources of Uvalde and Medina counties, Texas: U. S. Geol. Survey Water-Supply Paper 678, 146 pp.

SELLARDS, E. H., ADKINS, W. S., and PLUMMER, F. B. (1933) The geology of Texas, Vol. I, Stratigraphy: Univ. Texas Bull. 3232, Aug. 22, 1932, 1007 pp.

SHARPE, C. F. S. (1938) Landslides and related phenomena, Columbia Univ. Press, New York, 137 pp.

SHAW, W. M. (1931) Determination of CO_2 in soil carbonates—A modification of the official method: Jour. Assoc. Offic. Agr. Chemists, vol. 14, pp. 283–292.

STENZEL, H. B. (1938) The geology of Leon County, Texas: Univ. Texas Bull. 3818, 295 pp.

STEPHENSON, L. W. (1918) Contributions to the geology of northeastern Texas and southern Oklahoma: U. S. Geol. Survey Prof. Paper 120-H, pp. 129–163.

———————— (1929) Unconformities in the Upper Cretaceous series of Texas: Bull. Amer. Assoc. Petr. Geol., vol. 13, pp. 1323–1334.

———————— (1934) The genus *Diploschiza* from the Upper Cretaceous of Alabama and Texas: Jour. Paleont., vol. 8, pp. 273–280.

———————— (1937) Stratigraphic relations of the Austin, Taylor, and equivalent formations in Texas: U. S. Geol. Survey Prof. Paper 186-G, pp. 133–146.

APPENDIX

WELL DATA

HOLE 694

Location.—Falls County. Gregorio Basquez survey; about 3/8 mile northeast by east from Trinity Lutheran Church; 45 feet from southeast and 900 feet from northeast lines of Government-owned land. Landowner, U. S. Government (formerly A. Kuehl). Elevation of ground surface, 506.8 feet; total depth, 54.6 feet. Diameter, 13 inches.

Method and disposition.—Hand auger and hand-operated spudding bit with derrick. Drilling begun, June 1, 1939; completed, December 8, 1939. Driller, W.P.A. and C.C.C. crews. Uppermost 17.9 feet cased with 12¼-inch pipe; backfilled to 40.3 feet total depth and converted to observation well.

Remarks.—Large water supply for shallow wells of this size in this vicinity, but water carries about 6,000 p.p.m. total solids by rough analysis.

Log
(from field log, observations, and samples)

	Depth *Feet*	Thickness *Feet*
Recent alluvium—		
Top soil (under Bermuda grass sod)—black, sticky, contains streaks and patches of fine (visible) sand and a few pebbles	2.8	2.8
Terrace alluvium—		
Soil—black, contains very little sand, dry below 5 feet	5.8	3
Sub-soil—brownish gray to yellow; contains visible sand, fine gravel, and a few pebbles up to 1 inch in diameter; also soft white $CaCO_3$ concretions	8.5	2.7
Decayed alluvial marl—yellowish gray with rusty and black spots and streaks; gritty on chewing; pebbles up to 2 inches long; lumps of undecayed marl	11	2.5
Pecan Gap—		
Lower highly calcareous marl—		
Decayed residual marl—brownish gray with rusty spots and numerous joints with white decay; very slight grittiness on chewing	11.5	0.5
Sound residual marl—brownish gray, less rusty and more compact than preceding, conchoidal fracture, very faintly laminated	13.8	2.3
A little water at 12.9 feet after hole stood six days. Easily removed and did not reappear.		
Marl—alternating streaks or layers of brownish gray and blue gray, with blue gray gradually becoming dominant with increasing depth; dry	17.2	3.4
Marl—blue gray, uniform, hard, and dry; faintly laminated; poor conchoidal fracture; effervesces readily with dilute acid; slight grittiness between teeth disappears on long chewing; a few shell fragments	21.7	4.5
Water at 19.2 feet.		
"Intermediate" between marl and chalk—blue gray, harder than preceding; breaks with snap	29.3	7.6
Additional water at 25 feet.		
Much additional water at 27.2 feet; bailing necessary; apparently no additional water below 29.3 feet.		
Marl—greenish gray; hard but softer than the preceding "intermediate" material; apparently dry	31	1.7
"Intermediate", similar to that above 29.3 feet—blue gray, hard, apparently dry	33.6	2.6
Lower chalk—		
Chalk—blue gray, very hard; breaks with snap, fracture hackly, not conchoidal; texture coarse for chalk; numerous foraminifera and spines visible under hand lens; uniform, no lamination visible; apparently dry; occasional fossils, including one 3½-inch *Inoceramus*	42	8.4

	Depth *Feet*	Thickness *Feet*
Chalk—blue gray, very hard; contains streaks, lenses, and patches of greenish-gray, slightly softer, chalky marl; both chalk and marl contain invisible silt detectable on chewing; all becomes harder and chalkier with increasing depth but retains appearance of a breccia; abundant foraminifera and spines but few larger fossils; no glauconite	46.6	4.6
Chalk—marly chalk breccia, similar to preceding but more uniformly hard; contains tiny dark green spots of glauconite, increasing in amount with depth; also some pyrite, some invisible silt	50.85	4.25
Wolfe City—		
Silty marl—		
(Chalk just above contact contains broken pieces of silty marl. Silty marl just below contact contains rounded lumps and lenses (compressed burrows?) of chalk.)		
Silty marl—dark greenish gray (nearly black when wet), much softer than the chalk; shrinks, cracks, and hardens on drying; flaky, contains much invisible silt, easily felt on chewing; no free water; marl very uniform after first foot below chalk; no fossils except a few decayed shell fragments	54.6 T.D.	3.75

HOLE 1000

Location.—Falls County. Gregorio Basquez survey; on west bank of Brushy Creek about 10 feet south of bridge carrying County Road 339; about 2¼ miles west-northwest of Otto. Landowner, county right-of-way. Elevation of ground surface, 454 feet; total depth, 17.4 feet. Diameter, 12 inches approximately.

Method and disposition.—Hand auger and bars. Drilling begun, March 12, 1937; completed, April 14, 1937. Driller, W.P.A. crew. Cased with 6-inch pipe and converted to observation well.

Remarks.—Possibly all the strata below the alluvium in this hole should be included in the upper chalk if they are to be correlated with the interpretation of Hole 1010.

Log
(from field log and samples)

	Depth *Feet*	Thickness *Feet*
Recent and terrace alluvium—		
Soil—black, sandy and sticky	9.0	9.0
Ground water at 7 feet 4 inches.		
Marl—gray and yellow, with a few small rusty streaks; crumbly; contains much sand and numerous large and small pebbles	9.8	0.8
Pecan Gap—		
Upper highly calcareous marl?—		
Marl—brownish gray, with gray streaks and rusty stains; hard for marl; no sand or silt detectable on chewing; apparently dry	11.0	1.2
Upper chalk—		
Hard marl or "intermediate" between marl and chalk—blue gray; breaks with snap	12.7	1.7
Marl—brownish gray, with gray and rusty streaks; much softer than preceding	13.2	0.5
"Intermediate"—blue gray; same as 11 to 12.7 feet.	13.9	0.7
Chalk—blue gray; hard; no silt on chewing	14.5	0.6
Marl—yellow, with dark brown and rusty streaks; slightly moist	14.8	0.3
Chalk—blue gray; same as 13.9 to 14.5 feet	17.4 T.D.	2.6

HOLE 1010

Location.—Falls County. L. F. Reed survey; about 35 feet north of County Road 339 and about 35 feet east of Little Brushy Creek; about 2¼ miles west-northwest of Otto. Landowner, Mrs. F. B. Moore. Elevation of ground surface, 463.2 feet; total depth, 160.3 feet. Diameter, 13 inches to 24.9 feet; 8 inches from 24.9 feet to bottom.

Method and disposition.—Hand auger to 24.9 feet; earth socket (excavator) on cable tool rig (power operated) from 24.9 feet to bottom. Drilling begun, November 8, 1937; completed December 10, 1937. Driller, W.P.A. crew (by hand); B. J. Thompson, Waco (by machine). Uppermost 24.8 feet cased with 8-inch pipe; converted to observation well.

Remarks.—No water in hole at conclusion of drilling; about 0.7 foot of water observed January 3, 1938; water rose very slowly but continuously to depth 117.86 feet below ground surface at last observation, July 18, 1940; seepage apparently comes from upper part of hole.

Log
(from field log, observations, and samples)

	Depth *Feet*	Thickness *Feet*
Recent alluvium?—		
Top soil—dark brown; contains manure and many small hard $CaCO_3$ concretions	2.0	2.0
Terrace alluvium—		
Soil—black, less friable than preceding; contains a little sand and a few pebbles; also hard $CaCO_3$ concretions and soft black concretions	4.1	2.1
Sub-soil—gray, sandy, with a few thin streaks of sand; also numerous small pebbles and concretions	6.0	1.9
Marl—gray, with a few rusty spots and white concretions; very sandy; numerous pebbles, especially close to base	8.3	2.3
A little water in hole after standing over night; easily removed.		
Pecan Gap—		
Upper highly calcareous marl—		
Marl—yellow for first foot, then gray to brownish gray; hard for marl; contains no sand	16.5	8.2
Upper chalk—		
Soft chalk—blue gray; contains no sand	17.2	0.7
Marl—rusty, soft, moist	18.8	1.6
Soft chalk—blue gray; contains no sand; one or two thin streaks of rusty marl	22.8	4.0
Marl—soft, moist	23.2	0.4
Chalk—blue gray, hard, compact, fine grained	23.6	0.4
Marl—blue gray, soft, moist	23.9	0.3
Chalk—blue gray, hard, compact, fine grained	24.9	1.0
No record	26.3	1.4
Chalk—light blue, moderately hard, dry	28.8	2.5
Lower highly calcareous marl—		
Marl—light blue, a few shell fragments	30.4	1.6
Chalk—light blue, moderately hard	31.0	0.6
Marl—light blue	31.8	0.8
Hard marl or "intermediate" between marl and chalk—light blue, dry	35.2	3.4
Marl—blue gray; softer than preceding run but hard for marl; dry	43.9	8.7
Marl—blue gray, similar to preceding but slightly softer; unctuous, slightly moist, traces of fossils	48.7	4.8
Marl—similar to preceding but a little harder, dry	54.8	6.1
Hard marl or "intermediate"—blue gray, dry	56.6	1.8
Marl—blue gray, similar to preceding but a little softer; very uniform, no grit on chewing, slightly unctuous, dry; traces of fossils here and there	75.8	19.2
Marl—greenish gray, considerably softer than the preceding, slightly moist	79.4	3.6
Marl—blue gray, hard, similar to 56.6 to 75.8 feet; dry	82.9	3.5
Marl—greenish gray, softer, a few decayed shell fragments, slightly moist	86.6	3.7
Marl—blue gray, gradually becoming harder, dry; a few fossils, including *Inoceramus*, at 93 feet	93.7	7.1
Hard marl or "intermediate"—blue gray, no grit on chewing, dry	100.4	6.7
Hard marl or "intermediate"—similar to preceding but trace of grit on chewing; gradually becoming harder with depth; generally barren but a few fossil fragments at 116 and 118 feet; dry	123.0	22.6
Lower chalk—		
Soft chalk—light blue, harder than preceding, no grit on chewing, traces of fossils, dry	124.3	1.3
"Intermediate"—blue gray, a little softer than chalk, no fossils, dry	129.5	5.2

	Depth Feet	Thickness Feet
Chalk—light blue, hard, no grit on chewing, slightly unctuous, traces of fossils, dry	141.2	11.7
Chalk—light blue, a little softer than the preceding, trace of grit on chewing, dry	144.5	3.3
Chalk—light blue; contains much dark green glauconite, and a few pieces of dark grayish-black marl; gritty on chewing, dry	145.5	1.0
Wolfe City—		
Silty marl—		
Marl—dark grayish black, silty on chewing; contains white patches and streaks of glauconitic chalk; traces of fossils, dry	147.3	1.8
Marl—very dark blue gray; much fine silt on chewing but no visible sand; contains light gray spots and angular areas which are sandier and more calcareous	150.5	3.2
Marl—dark blue gray; much fine silt on chewing but no visible sand; compact and tough, not brittle; uniform, a few decayed fossils, dry	160.3 T.D.	9.8

MICROSCOPIC FOSSILS

Determinations by laboratory of Humble Oil & Refining Company, Houston, Texas, under direction of F. W. Rolshausen. Samples examined were selected from material obtained by means of a hand auger, a pipe driven into the bottom of the hole, or an earth socket (excavator) churned on a cable tool drilling machine.

	Depth
Pecan Gap—	
Light-buff and white chalky marl	11′ 9″– 12′ 2″
Frondicularia sp.; Robulus sp.; Globigerina cretacea; Nodosaria sp.; Planulina taylorensis; Bolivinoides decorata; Anomalina henbesti; Guembelina globifera; Globorotalia micheliniana; Textularia sp.; Globotruncana arca; Heterostomella americana; Gyroidina depressa; Dorothia bulletta; Clavulina triangulata	
Light bluish-gray chalky marl. Same fossils as preceding plus *Bulimina* sp. and *Cassidulina* sp. (2 samples)	22′ 6″; 27′ 9″– 28′ 9″
Bluish-gray marl. Same fossils as preceding plus *Marginulina* sp.	43′11″– 46′ 4″
Light bluish-gray chalky marl. Same fossils as preceding plus *Kyphopyxa christneri*	79′ 5″– 81′
Bluish-gray chalky marl; same fossils as preceding (2 samples)	100′ 5″–102′ 2″; 132′10″–133′ 9″
Light gray marly chalk; same fossils as preceding	143′ 6″–144′10″
Wolfe City—	
Medium gray shaly marl	146′ 2″–147′ 4″
Globigerina cretacea; Ammobaculites sp.; Planulina taylorensis; Globotruncana arca; Robulus sp.; Trochammina sp.; Clavulina triangulata	
Medium gray shaly marl. Same fossils as preceding plus *Robulus taylorensis* and *Nodosaria* sp.	157′ 8″–160′ 3″

HOLE 1011

Location.—Falls County. H. Fanthorp survey; on southwest side of County Road 328A, about 500 feet southeast along this road from Gaging Station Y and about 3,300 feet northwest along this road from County Road 337; about 2¾ miles east of Riesel. Landowner, U. S. Government (formerly Otto Stieg). Elevation of ground surface, 526.4 feet; total depth 201 feet. Diameter, 14 inches to 32.1 feet; 8 inches from 32.1 feet to bottom.

Method and disposition.—Hand auger to 33.3 feet; earth socket (excavator) on cable tool rig (power operated) from 33.3 feet to bottom. Drilling begun, October 19, 1937; completed, December 2, 1937. Driller, W.P.A. crew (by hand); B. J. Thompson, Waco (by machine). Cased with 8-inch pipe to depth 32.1 feet; 6-inch pipe from surface to total depth, with perforations in the sandy marl from depth

93.7 to 103 feet and from 115.7 feet to bottom; water from chalk sealed off; converted to observation well.

Remarks.—Well bailed dry after casing January 3, 1938; water rose continuously until it reached equilibrium at 9.04 feet below ground level on March 28, 1939; water very salty; about 12,000 p.p.m. total solids.

Log
(from field log, observations, and samples)

	Depth *Feet*	Thickness *Feet*
Pecan Gap—		
Residual soil—		
Top soil—black, sticky	1.0	1.0
Sub-soil—dark gray to light gray, dry and powdery	3.5	2.5
Lower highly calcareous marl—		
Decayed marl or "intermediate" between marl and chalk—crumbly, a few shell fragments	5.0	1.5
Lower chalk—		
"Intermediate" between marl and chalk—light tan, whiter on drying; disintegrated, lumps moderately hard	8.5	3.5
Chalk—light tan, disintegrated, lumps hard; harder and more brittle with increasing depth; moist	14.5	6.0
Chalk—disintegrated, very crumbly and soft	15.7	1.2
Ground water at 15.5 feet.		
Chalk—light tan, hard and brittle, moist	17.1	1.4
Chalk—light tan with rusty and gray patches, disintegrated, soft, wet	18.3	1.2
Wolfe City—		
Silty marl—		
Silty marl—brown, with rusty and light gray streaks; invisible silt throughout, detected on chewing, moist	23.3	5.0
Silty marl—chiefly brown, with blue-black streaks and lenses; the blue black generally more compact and less moist; sand just visible at a few places, occasional streaks of crystalline gypsum	33.3	10.0
Silty marl—blue black with some rusty streaks	43.0	9.7
Silty marl—blue gray; much silt throughout, barely visible to eye but easily to hand lens; no fossils, dry	55.5	12.5
Silty marl—blue gray, similar to preceding but contains a few small shells; silt a little coarser toward bottom	65.8	10.3
Sandy marl—		
Sandy marl—blue gray, rich in definitely visible sand; contains a few small pieces of hard, blue, calcareous sandstone; also a few fossils, dry	79.1	13.3
Sandy marl—blue gray, similar to preceding but a little harder and richer in fossils, chiefly fragments of *Inoceramus*, dry	86.3	7.2
Sandy marl—blue gray, plainly visible sand throughout, also numerous thin laminae of very fine white sand; lenses of hard calcareous sandstone up to 1 inch thick; slightly moist at about 95 feet and at about 100 feet; elsewhere dry; fossils scarce	111.6	25.3
Sandy marl—blue gray, softer than the preceding, very sandy, visible sand throughout, also in distinct laminae and pockets; very little hard sandstone; porous, moist at many places, no fossils, effervesces slowly with dilute HCl	141.5	29.9
Sandy marl—blue gray, very sandy; generally similar to preceding run but contains numerous pieces of calcareous sandstone in various stages of consolidation; no fossils, slightly moist	153.4	11.9
Sandy marl—blue gray, alternating sandy and clayey laminae, this material alternating on a larger scale with harder, finer[12] beds up to 2 inches thick; very little hard sandstone; numerous decayed shell fragments, dry	175.8	22.4
Sandy marl—blue gray; laminated like the preceding, but laminae are more lenticular and contain "knots" of calcareous sandstone, structure reminiscent of some mica schist; fossils scarce, dry	188.5	12.7
Sandy marl—blue gray, very sandy, irregular laminae and pockets of coarser gray sand, a few small pieces of hard sandstone; fossils scarce, moist in places, tastes of gypsum	195.8	7.3

[12]The terms coarser and finer as used in this description are relative; actually none of the sand described is any coarser than medium sand (0.25 to 0.50 mm) and most of it is finer.

	Depth *Feet*	Thickness *Feet*
Sandy marl—blue gray, finer and harder than preceding run, a few pieces of calcareous sandstone of various degrees of consolidation, dry	198.4	2.6
Sandy marl—blue gray; irregular laminae, with lenses of coarser sand and tiny knots of hard calcareous sandstone; structure like mica schist, very slightly moist	201.0 T.D.	2.6

MICROSCOPIC FOSSILS

Determinations by laboratory of Humble Oil & Refining Company, Houston, Texas, under direction of F. W. Rolshausen. Samples examined were selected from material obtained by means of a hand auger, a pipe driven into the bottom of the hole, or an earth socket (excavator) churned on a cable tool drilling machine.

		Depth
Pecan Gap—		
White and buff marly chalk (5 samples)		6′ 0″; 7′ 3″; 11′ 6″; 13′ 2″; 15′ 0″
Globigerina cretacea	Heterostomella sp.	
Frondicularia sp.	Marginulina sp.	
Kyphopyxa christneri	Robulus sp.	
Planulina taylorensis	Bolivinoides decorata	
Anomalina henbesti	Bulimina sp.	
Globorotalia micheliniana	Pullenia sp.	
Nodosaria affinis	Gyroidina sp.	
Clavulina triangulata	Nodosaria sp.	
Globotruncana arca		
White and buff chalky marl with a trace of glauconite included; same fossils as above		16′ 6″
As preceding but with more glauconite; same fossils		17′ 8″
As preceding but with brown marl; same fossils		18′ 3″
Pecan Gap—Wolfe City transition zone—		
Buff marl, trace of glauconite; contains both Pecan Gap and Wolfe City fossils which are considered in place (2 samples)		19′ 6″– 19′11″; 21′ 8″
Globorotalia micheliniana	Robulus taylorensis	
Bulimina sp.	Bolivinoides decorata	
Planulina taylorensis	Nodosaria vertebralis	
Trochammina sp.	Gyroidina sp.	
Globotruncana arca	Fish teeth	
Pullenia sp.	Haplophragmoides sp.	
Wolfe City—		
Buff and bluish-gray shaly marl, trace of glauconite and sand included		23′ 4″– 23′ 9″
Planulina taylorensis	Robulus taylorensis	
Bulimina sp.	Robulus sp.	
Nodosaria sp.	Haplophragmoides sp.	
Globotruncana arca	Verneuilina sp.	
Guembelina globifera		
Bluish-gray and buff shaly marl, trace of glauconite. Same fossils as preceding plus *Clavulina triangulata* and ostracodes		26′ 6″– 26′11″
Bluish-gray marly shale, trace of sand (2 samples)		27′ 2″– 27′ 6″; 29′ 9″– 30′ 2″
Ammobaculites sp.	Robulus taylorensis	
Clavulina triangulata	Robulus sp.	
Gaudryina sp.	Kyphopyxa christneri	
Globigerina cretacea	Haplophragmoides sp.	
Guembelina globifera	Planulina taylorensis	
Bigenerina sp.	Anomalina henbesti	
Nodosaria sp.	Gyroidina sp.	
Globotruncana arca	Ostracodes	
Chocolate-colored and bluish-gray shaly marl, trace of selenite and sand. Same fossils as preceding plus *Nodosaria affinis* and *Saracenaria* sp.		33′ 3″
Same as preceding with a few small sandstone fragments included; same fossils as preceding		38′ 0″
Bluish-gray marly shale, trace of sand. Same fossils as preceding plus *Loxostoma* sp.		38′ 0″– 41′ 0″
Same as preceding but with more sand; same fossils (2 samples)		43′ 0″– 45′ 6″; 46′ 6″– 48′ 2″
Gray shaly marl, trace of sand; same fossils (4 samples). Sample from 57′3″–59′2″ also contains *Flabellammina* sp.		50′ 0″– 52′ 0″; 53′ 9″– 55′ 6″; 57′ 3″– 59′ 2″; 60′ 6″– 62′ 6″

	Depth		
Gray sandy marl; fewer fossils (7 samples)	64′ 0″– 65′ 9″;	65′ 9″– 67′ 6″;	68′ 8″– 70′ 6″;
	72′ 3″– 73′ 8″;	75′ 4″– 77′ 3″;	79′ 1″– 80′ 7″;
			82′ 0″– 83′ 6″
Same as preceding but not quite as sandy; same fossils (4 samples)	84′10″– 86′ 4″;	88′ 4″– 90′ 0″;	91′ 8″– 93′ 7″;
			95′ 4″– 96′ 9″
Gray sandy marl with small sandstone and limestone nodules included; same fossils as preceding			98′ 4″– 99′ 7″
Gray slightly sandy marl; same fossils (2 samples)		101′ 1″–102′ 8″;	103′10″–104′11″
Same as preceding with possibly a little more sand; same fossils (14 samples)	106′ 7″–108′ 2″;	118′ 2″–111′ 7″;	113′ 9″–116′ 1″;
	118′ 5″–120′ 7″;	122′ 6″–124′ 5″;	125′11″–127′10″;
	129′ 4″–131′ 0″;	132′ 7″–134′ 0″;	136′ 0″–137′ 8″;
	139′ 7″–141′ 6″;	143′ 3″–145′ 2″;	147′ 0″–147′ 7″;
		149′ 6″–151′ 0″;	152′ 9″–154′ 0″
Same as preceding but with less sand; same fossils (7 samples)	155′ 0″–156′ 8″;	158′ 6″–160′ 3″;	161′10″–163′ 6″;
	164′11″–166′10″;	168′ 9″–170′ 4″;	172′ 3″–173′10″;
			175′10″–177′ 7″
Same as preceding but with more sand; same fossils (5 samples)	179′ 3″–180′ 9″;	182′ 5″–183′ 8″;	185′ 2″–186′ 6″;
		188′ 6″–190′ 6″;	192′ 6″–194′ 1″
Same as preceding but with even more sand; same fossils			195′10″–197′ 3″
Same as preceding			198′ 5″–200′ 6″

Planulina taylorensis	Gyroidina sp.
Robulus sp.	Nodosaria affinis
Robulus taylorensis	Globigerina cretacea
Clavulina triangulata	Ostracodes
Globotruncana arca	Oysters

HOLE 1012

Location.—McLennan County. D. Sanchez survey; about 200 feet north of County Road 233, about 1½ miles east-northeast of business section of Riesel. Landowner, Ruby N. Turner (formerly C. B. Turner). Elevation of ground surface, 517.8 feet; total depth, 160.5 feet. Diameter, 11½ inches to 20.2 feet; 8 inches from 20.2 feet to bottom.

Method and disposition.—Hand auger to 20.9 feet; earth socket (excavator) on cable tool rig (power operated) from 20.9 feet to bottom. Drilling begun, October 21, 1937; completed, December 24, 1937. Driller, W.P.A. crew (by hand); B. J. Thompson, Waco (by machine). Cased with 8-inch pipe to 20.2 feet; 6-inch pipe from 14.5 feet to total depth, with perforations from 88.6 to 99.3 feet and from 108.7 feet to bottom; converted to observation well.

Remarks.—Hole bailed dry December 30, 1937, after casing; water rose continuously until it reached equilibrium at 19.38 feet below ground level on July 7, 1938; water very salty; about 10,500 p.p.m. total solids.

Log
(from field log, observations, and samples)

	Depth *Feet*	Thickness *Feet*
Residual soil and sub-soil, mixed with remnants of terrace alluvium?—		
Top soil—black, slightly sandy at surface; gravel scattered over ground surface near by	1.0	1.0
Sub-soil—dark yellowish brown, becoming more greenish brown with depth; contains small soft, white concretions and occasional rounded quartzite and flint pebbles; dry; very hard	5.2	4.2
Wolfe City—		
Sandy marl—		
Sandy marl—yellow, hard and tough; rich in clay, with small spots of gray visible sand; contains white $CaCO_3$ concretions; no pebbles	6.1	0.9
Sandy marl—grayish brown; hard and tough; barely visible sand throughout, also in small spots; marl thinly laminated; many white $CaCO_3$ concretions in upper part; a few pieces hard calcareous sandstone in lower part; no pebbles; dry	9.7	3.6

	Depth *Feet*	Thickness *Feet*
Sandy marl—grayish brown; 1-inch layers of marl containing barely visible sand throughout, laminated rusty and gray, alternating with thin layers of rusty and gray fine sand; occasional pieces of hard calcareous sandstone; slightly moist in spots	16.5	6.8
Sandy marl or marly sand—grayish black to bluish black with some rusty streaks; soft, friable, and somewhat floury; much sandier than preceding; not much hard sandstone; slightly moist in spots	18.0	1.5
Sandy marl—blue gray, with occasional rusty streaks; texture and structure generally similar to 9.7 to 16.5 feet; contains pieces of hard, blue calcareous sandstone up to 1 inch thick; generally dry	20.1	2.1
Sandy marl—bluish black to greenish black; darker, finer,[13] and richer in clay than the preceding; very tough; effervesces only slowly with dilute HCl; no hard sandstone	20.9	0.8
No record	21.7	0.8
Sandy marl—dark blue gray, very sandy, hard (for marl) and compact; pieces of hard sandstone up to 1 inch thick; also some incompletely cemented; dry	25.0	3.3
Sandy marl—dark blue gray, very sandy, faintly laminated; visible sand in laminae, small pockets, and distributed throughout; a little hard sandstone; fossils scarce; slightly moist	31.3	6.3
Sandy marl—dark blue gray, very sandy, rather friable; sand in pockets and lenses, not distinctly laminated; effervesces vigorously with acid; slightly moist	34.0	2.7
Sandy marl—very dark blue gray, darker, sandier, and coarser than the preceding; sand in thin laminae and tiny lenses; a little poorly consolidated calcareous sandstone; fossils scarce; very moist	46.2	12.2
Sandy marl—dark blue gray, very sandy but finer textured and more calcareous than the preceding; generally similar to 31.3 to 34.0 feet; a little hard sandstone; no fossils; slightly moist	51.3	5.1
Ground water appeared in hole after standing at this depth for 40 hours; also every morning thereafter; very slow seepage; water easily removed during operations.		
Sandy marl—dark blue gray, very sandy; distinct laminae of coarser and finer gray sand; also lenses of soft and hard sandstone; slightly moist	54.5	3.2
Sandy marl—dark blue gray, finer and more uniform than the preceding; a few lenses of clean sand; no hard sandstone; very slightly moist	57.2	2.7
Sandy marl—dark blue gray, still finer and more uniform; sand just visible; faintly laminated; rich in decayed shell fragments; dry	60.8	3.6
Sandy marl—dark blue gray, coarser and sandier than the preceding; very slightly moist	61.8	1.0
Sandy marl—blue gray, similar to 57.2 to 60.8 feet; sand just visible; dry	65.3	3.5
Sandy marl—dark blue gray, coarser than the preceding; thin dark gray and light gray laminae, the latter richer in sand; a few decayed fossils; slightly moist	73.4	8.1
Sandy marl—dark blue gray, gradually becoming finer downward; a little soft and hard sandstone; very few fossils; dry	76.8	3.4
Sandy marl—dark blue gray, alternating layers, from about 6 inches to 3 feet thick, of coarser and finer material; the coarser layers carry pockets of coarser sand (moist) and laminae of finer sand (dry) and are more calcareous; the finer layers (dry) carry barely visible sand and are more uniform; occasional hard calcareous sandstone up to 2½ inches thick; occasional shells, including *Inoceramus*, and shell fragments	98.3	21.5
Sandy marl—blue gray, fine grained and compact, fairly uniform, indistinctly laminated, not very calcareous, a little hard sandstone, numerous fossil fragments, dry	107.9	9.6
Sandy marl—dark blue gray; alternating thin layers and laminae rich in coarser and finer sand; coarser layers slightly moist, the remainder dry; a little hard sandstone; fossils scarce	122.7	14.8
Sandy marl—dark blue gray, generally similar to 76.8 to 98.3 feet; alternating thick, indistinctly laminated, coarser and finer layers; the former carrying pockets of moist, coarser sand; occasional thin streaks of hard calcareous sandstone; occasional shells and shell fragments; generally compact and tough	136.2	13.5

[13] The terms finer and coarser as used in this description are relative; actually none of the sand described is any coarser than medium sand (0.25 to 0.50 mm), and most of it is finer.

	Depth Feet	Thickness Feet
Sandy marl—dark blue gray; distinct coarser (light gray) and finer (darker) laminae, the former more calcareous; also pockets of greenish-gray, still coarser sand, which are moist; no hard sandstone; very few fossils; compact	141.7	5.5
Sandy marl—dark blue gray, similar to preceding but finer; sand barely visible except in coarser laminae and pockets; very little hard sandstone; some fossils; hard, compact, and tough	146.9	5.2
Sandy marl—dark blue gray; more or less distinct coarser and finer laminae, many of them composed of thin sheets of hard or soft calcareous sandstone, texture in general very fine; very few fossils; generally dry	155.8	8.9
Sandy marl—dark blue gray, a little coarser than the preceding; distinct laminae and also pockets of coarser sand, which are moist and taste salty; a few laminae of hard sandstone; fossils scarce; most of material dry	160.5 T.D.	4.7

HOLE 1020

Location.—Falls County. Jose Maria Sanchez survey; on chalk ledge in bed of Brazos River, on the right (southwest) side of the low-water channel, just below the lower of the two sharp bends below the mouth of Perry Creek; about 4 miles southwest by south from the courthouse at Marlin. Landowner, J. E. Masters. Elevation of ground surface, approximately 321 feet; total depth, 17.5 feet. Diameter, 6 feet.

Method and disposition.—Dug by hand. Well begun, April 21, 1938; completed, May 19, 1938. Dug by W.P.A. crew. Filled.

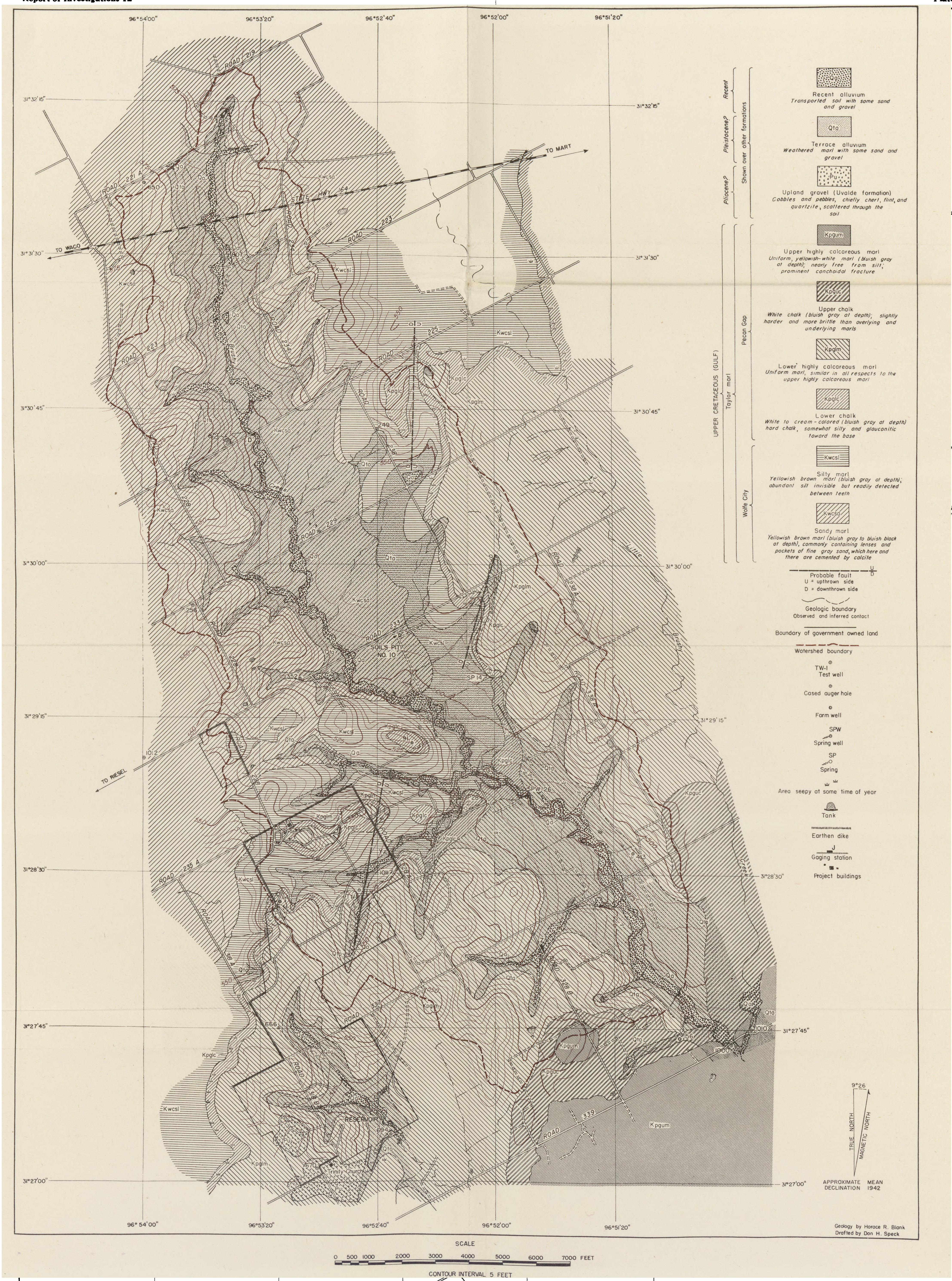
Remarks.—Constant flow of ground water entered hole through joints in chalk, necessitating frequent pumping during excavation work; after standing 16 hours, water level in hole was usually 2 to 4 feet higher than in adjacent Brazos River.

Log
(from field log, observations, and samples)

	Depth Feet	Thickness Feet
Pecan Gap—		
Lower chalk—		
Chalk—chiefly blue gray, with irregular areas of white to cream color; both become lighter colored after a few hours exposure; hard, compact, fine grained; no grit after chewing	4.0	Approx. 4.0
Ground water at 0.5 foot.		
Chalk—blue gray, except along joints, where cream color continues; very hard; not so brittle as preceding; contains patches, sandy in appearance, which seem to be aggregates of microscopic fossils; no grit after long chewing; occasional shells	10.5	6.5
Chalk—blue gray, slightly coarser than preceding, more brittle, hard, rings under hammer; contains pockets of very fine "sand," consisting chiefly of calcareous shells but also a little glauconite and angular quartz; frequent fossils, chiefly *Inoceramus* and *Baculites* (flattened)	12.7	2.2
Chalk—blue, finer grained, harder; gritty on chewing but no sand pockets; glauconite throughout	13.2	0.5
Chalk—blue, similar to preceding but very fossiliferous; numerous shells, casts, and fragments of *Inoceramus*, *Baculites*, and others not determined; glauconite and pyrite (or marcasite)	14.1	0.9
Contact zone—interbedded streaks of glauconitic chalk and black, moderately soft, silty marl; a few angular pieces of marl in the chalk and a few lenses of chalk in the marl; sharp contact between the materials in every case	14.5	0.4

	Depth *Feet*	Thickness *Feet*
Wolfe City—		
Silty marl—		
Silty marl—black, moderately soft; can be carved by fingernail; breakage somewhat platy parallel to bedding; much invisible silt uniformly distributed throughout (detected on chewing); on drying becomes harder, lighter in color, and tends to check and split parallel to bedding; upper part contains numerous cylindrical burrows up to about ¾-inch diameter filled with glauconitic chalk	16.2	1.7
Clay—bluish black to purplish blue; soft, contains pyrite (or marcasite) and slickensides; contains lenses of marl; apparently a fault gouge	16.3	0.1
Silty marl—black; same as 14.5 to 16.2 feet but without chalk-filled burrows; very uniform; fossils scarce	17.5 T.D.	1.2

INDEX



96°54'00" 96°53'20" 96°52'40" 96°52'00" 96°51'20"

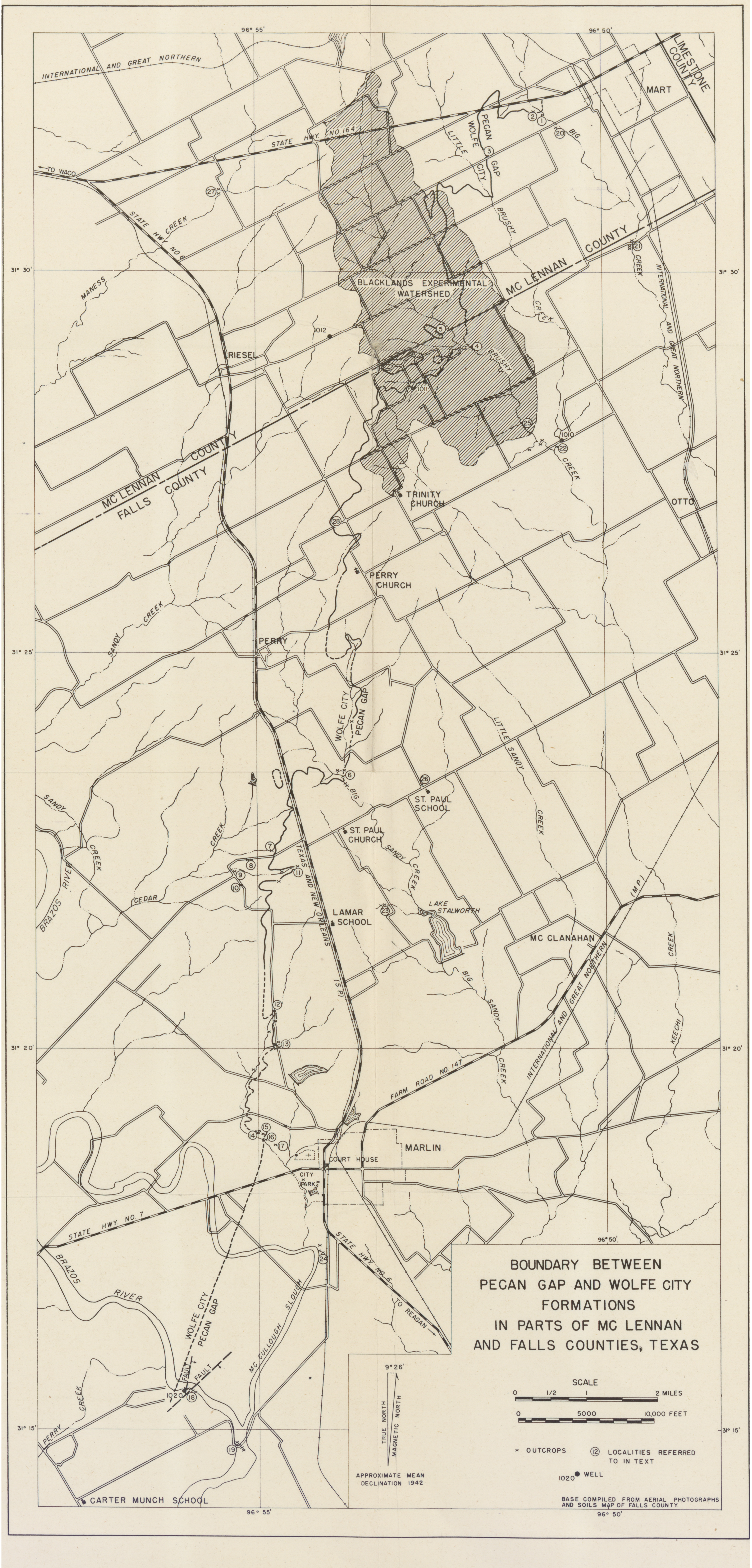
Geology by Horace R Blank
Drafted by Don H Speck

SCALE

0 500 1000 2000 3000 4000 5000 6000 7000 FEET

CONTOUR INTERVAL 5 FEET

GEOLOGIC MAP OF BLACKLANDS EXPERIMENTAL WATERSHED NEAR WACO, TEXAS


BOUNDARY BETWEEN
PECAN GAP AND WOLFE CITY
FORMATIONS
IN PARTS OF MC LENNAN
AND FALLS COUNTIES, TEXAS
SCALE
0 1/2 1 2 MILES
0 5000 10,000 FEET
× OUTCROPS
12 LOCALITIES REFERRED TO IN TEXT
1020 ● WELL
TRUE NORTH
MAGNETIC NORTH
9°26'
APPROXIMATE MEAN DECLINATION 1942
BASE COMPILED FROM AERIAL PHOTOGRAPHS AND SOILS MAP OF FALLS COUNTY
96° 55'
96° 50'
31° 30'
31° 25'
31° 20'
31° 15'
LIMESTONE COUNTY
MART
MC LENNAN COUNTY
FALLS COUNTY
BLACKLANDS EXPERIMENTAL WATERSHED
INTERNATIONAL AND GREAT NORTHERN
STATE HWY NO 164
TO WACO
STATE HWY NO 6
STATE HWY NO 7
FARM ROAD NO 147
TEXAS AND NEW ORLEANS (S P)
RIESEL
PERRY
TRINITY CHURCH
PERRY CHURCH
OTTO
ST. PAUL SCHOOL
ST. PAUL CHURCH
LAMAR SCHOOL
LAKE STALWORTH
MC CLANAHAN
MARLIN
COURT HOUSE
CITY PARK
CARTER MUNCH SCHOOL
TO REAGAN
BRAZOS RIVER
MANESS CREEK
SANDY CREEK
CEDAR CREEK
LITTLE BRUSHY CREEK
BRUSHY CREEK
BIG CREEK
LITTLE SANDY CREEK
BIG SANDY CREEK
KEECHI CREEK
PERRY CREEK
MC CULLOUGH SLOUGH
PECAN GAP
WOLFE CITY
FAULT
1010
1011
1012
1020